ENGINEERING EXPERIMENT STATION
OF THE GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

2 b
12-C.

QUARTERLY REPORT NO. 1-7
AND
FINAL REPORT

PROJECT NO. A-203

RESEARCH ON ELECTRONIC CINÉFLUOROGRAPHY

J. H. TOLAN
PROJECT DIRECTOR, FEB. 15, 1955-MAY 1956

A. E. WILLIAMSON
PROJECT DIRECTOR, MAY 1956-MARCH 15, 1957

CONTRACT NO. DA-36-039-sc-64615

DEPARTMENT OF THE ARMY PROJECT: 3-99-04-052
SIGNAL CORPS PROJECT: 195B

FEB. 15, 1955-MARCH 15, 1957

CONTENTS

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY REPORT NO. 1

PROJECT NO. A-203

RESEARCH ON ELECTRONIC CINEFLUOROGRAPHY

- o - o - o - o -

CONTRACT NO. DA-36-039-sc-64615

DEPARTMENT OF THE ARMY PROJECT: 3-99-04-052

SIGNAL CORPS PROJECT: 195B

- o - o - o - o -

MAY 31, 1955

PLACED BY THE U. S. ARMY
SIGNAL CORPS ENGINEERING LABORATORIES
FORT MONMOUTH, NEW JERSEY

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY REPORT NO. 1

PROJECT NO. A-203

RESEARCH ON ELECTRONIC CINÉFLUOROGRAPHY

Prepared by

J. H. TOLAN and J. L. BROWN

Object: To determine diagnostic suitability
of electronic cinéfluorography

PLACED BY THE U. S. ARMY
SIGNAL CORPS ENGINEERING LABORATORIES
FORT MONMOUTH, NEW JERSEY

FEBRUARY 15 to MAY 15, 1955

TABLE OF CONTENTS

This Report Contains 17 Pages

LIST OF FIGURES

I. PURPOSE

The purpose of this project is to provide information regarding the suitability of electronic-image-amplification use in cinéfluorography. The project consists of an experimental study of commercially available electronic-image-amplifying devices, which will be used in a system incorporating a motion picture camera for the purpose of recording the image formed on a fluorescent surface by an X-ray beam.

The work is divided into four principal tasks as follows:

(1) the evaluation of nonelectronic cinéfluorography to obtain basic information on contrast, exposure factors, detail and over-all system efficiency;

(2) the evaluation of electronic cinéfluorography to determine which diagnostic procedures are possible with image amplification and to correlate information obtained in task (1);

(3) the fabrication of a laboratory model using an image-amplifying tube; and

(4) the development of accessory items which would be useful in analyzing film results if time and funds permit.

II. ABSTRACT

The modifications made in the existing cinéfluorographic system are described herein. These consisted of (1) the replacement of the X-ray tube stand with a more rigid one, (2) the design and construction of a lens mount to accommodate a Wray f/0.71 or a Bausch and Lomb f/0.9 lens, (3) the reinforcement of the metal carriage which supports the screen and camera assembly and (4) the addition of a track guide for camera alignment.

A type of standard radiographic phantom was constructed, and some preliminary tests were performed.

III. CONFERENCES

On 24 and 25 February 1955, J. H. Tolan and J. L. Brown visited the X-ray Division, Westinghouse Electric Corporation, Baltimore, Maryland. Problems associated with electronic cinéfluorography were discussed with Mr. Walter Lusby and Mr. Fred Euler, who have been engaged in the development of a commercial cinéfluorographic unit using an image-amplifier tube. The apparatus under development by Westinghouse utilizes a 16-mm motion picture camera and lens system to view the output phosphor of the image amplifier, but no study had been made to compare the diagnostic results with those obtained with a 35-mm camera and lens system.

IV. FACTUAL DATA

A. Introduction

Within a few years after the discovery of X-rays, the first attempts were made to record fluoroscopic sequence images of moving objects on film. The inherent difficulties were many. The basic problem was one of producing a light image corresponding to the X-ray image of sufficient intensity to be recorded on film at a framing speed fast enough to indicate rapid anatomical changes. For example, the conversion efficiency of fluorescent materials is quite low and, therefore, requires (1) that the X-ray generator be operated at or near its maximum rated energy, (2) that a special high-speed lens be used and (3) that the camera framing speed be reduced to permit more light to reach each frame of the most sensitive film available. The high level X-ray exposure thus required also presents a radiation hazard to both patient and operator.

These difficulties and their practical solutions have been described by many investigators (1-11). As a result of these investigations, it is now possible to fabricate a cinéfluorographic unit using a system composed of heavy duty X-ray tube and generator, fluorescent screen, high-speed refracting lens and camera. Unfortunately, such a system is costly and, as a consequence, has not been widely used.

Recent development of image-amplifying tubes has suggested the possibility of use of such devices in cinéfluorography. If as suggested, the image-amplifying tube provides a substantial increase in brightness, the capacity of the X-ray tube and generator may be reduced, thus reducing the cost of the system as well as the radiation exposure to the patient. However, the field of view of the image amplifier is small (5 inches in diameter), and the question naturally arises as to whether or not the tube will "see" enough to provide a diagnostic film record.

This project's approach to the question of diagnostic suitability is to first obtain the information on the basic factors of interest in the nonelectronic system. The unit which was available at the start of this work was not entirely suitable for the measurements to be performed. Consequently, extensive modification of the unit was undertaken. In addition, a type of standard radiographic test object or "phantom" has been constructed which will permit comparative measurements between the direct and the electronic cinéfluorographic units.

B. Description of Apparatus

The modified nonelectronic cinéfluorographic unit is shown in Figure 1. The X-ray system incorporates a Machlett, "Super Dynamax" X-ray tube with both 1- and 2-mm focal spots. The tube was originally mounted on a side rail tube-stand, which lacked sufficient rigidity for precise positioning. This stand was replaced by a floor-ceiling rail design of more substantial construction which has resulted in considerable improvement in the system's rigidity.

In operation the test object or patient is supported by the table shown in Figure 1, and the portion of the subject to be examined is positioned over the Plexiglas window built flush into one end of the table. The Plexiglas has a durable surface, does not appreciably scatter the X-ray beam and permits visual alignment of the camera mechanism underneath.

The camera mechanism proper is supported by a four-wheeled carriage with provision for both locking the wheels for stability and changing the height of the camera mechanism to permit removal from beneath the table. This carriage was modified for increased stability by the addition of a pair of steel beams parallel with and beneath the top rails of the carriage.

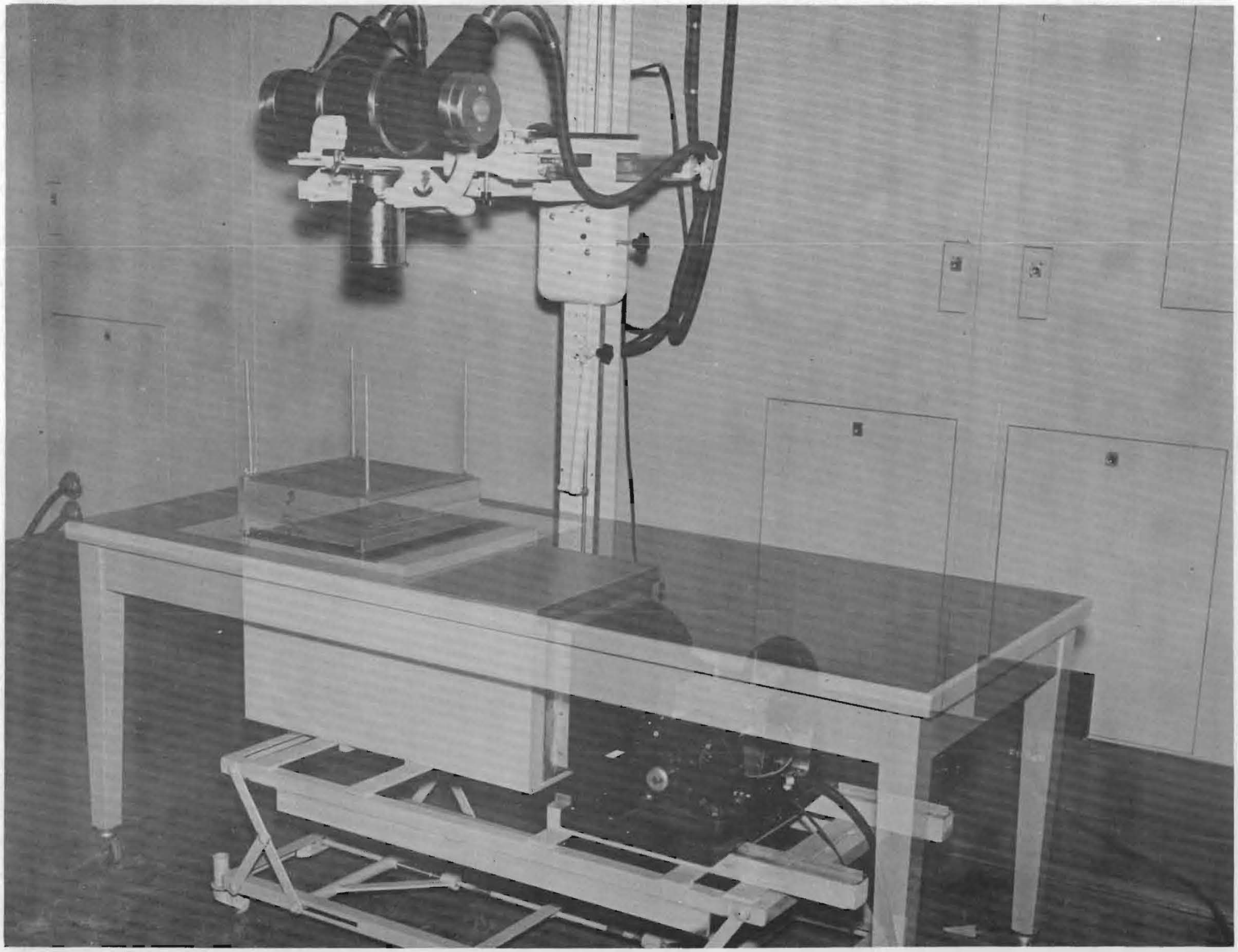


Figure 1. Nonelectronic Cinéfluorographic Apparatus.

The camera box contains a Patterson "E-2" fluorescent screen, which is positioned immediately beneath the Plexiglas window. The light image formed by the X-ray beam on this screen is reflected 90 degrees by a front-surface aluminized mirror. This image is then viewed by the camera facing into the open end of the box through a connecting bellows.

The camera is a 35-mm aircraft gun camera which has been extensively modified. The two lenses which have been available for use are the Wray f/0.71 and Bausch and Lomb f/0.9. These two lenses vary widely in optical and physical characteristics. Consequently, the design and construction of a lens mount permitting easy interchange of lenses was necessary. This mount and the two lenses are shown attached to the camera in Figure 2.

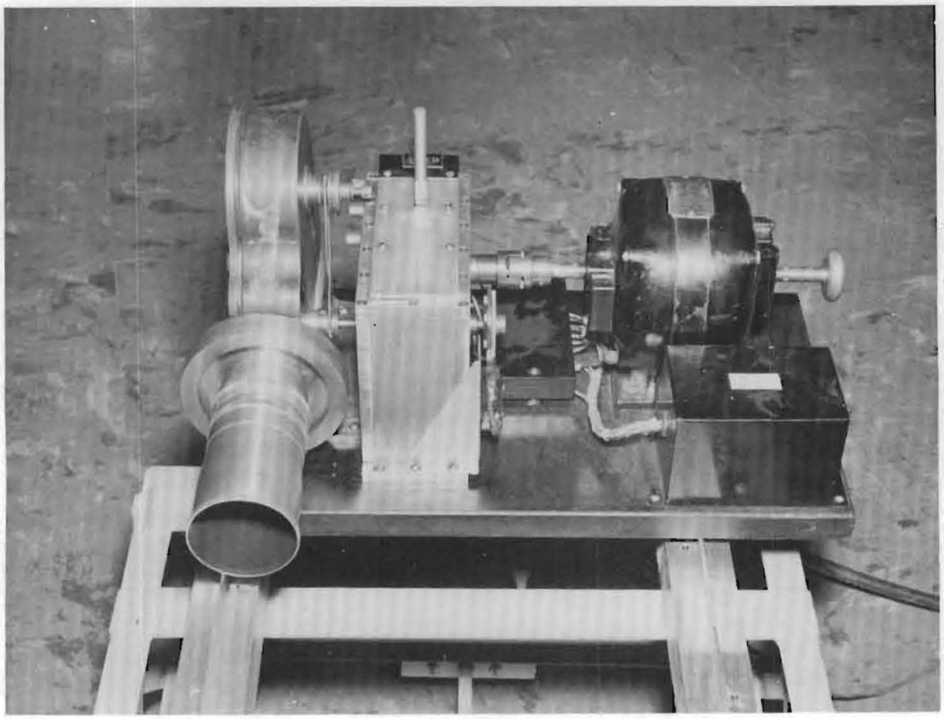
The camera is driven by an 1800-rpm synchronous motor through a gear train, which permits camera framing speeds of 7.5, 15 and 30 frames per second.

Geared in with the drive is a cam and microswitch assembly controlling a Liebel-Flarsheim, Thyr-X timer which interrupts the primary of the X-ray transformer during the camera pull-down time. This interruption of the X-ray beam reduces the exposure to the patient, reduces the load on the X-ray tube and permits camera operation without a mechanical shutter.

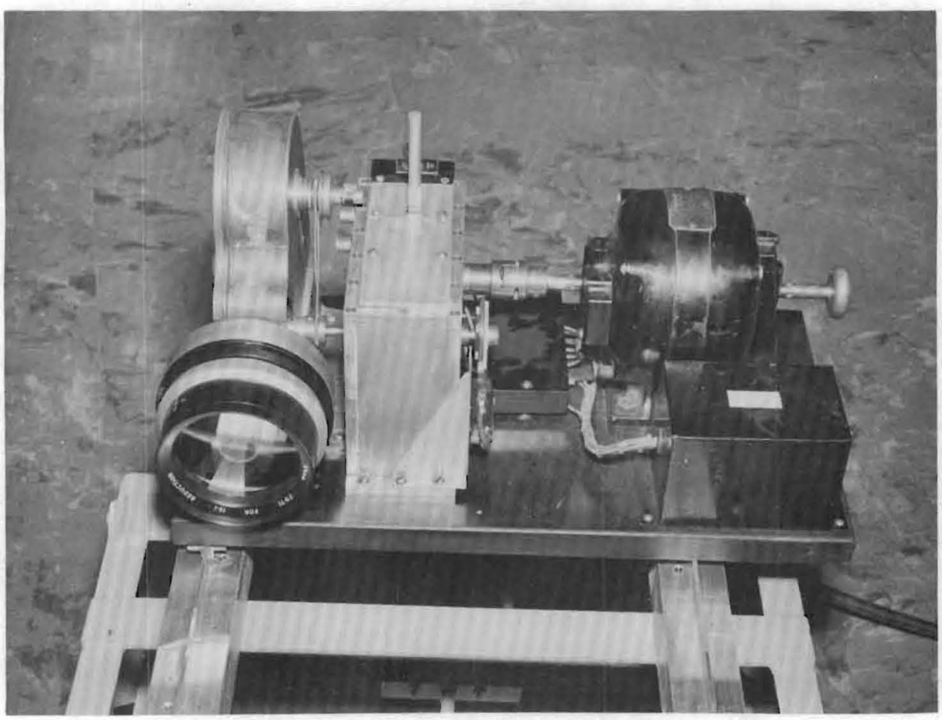
The camera and the drive mechanism were mounted upon a section of die board which was placed at one end of the carriage. This was modified to the extent of adding tracks to the carriage permitting accurate positioning of the camera with respect to the screen.

The Thyr-X timer and X-ray control panel are shown in Figure 3.

The standard radiographic test object or phantom was constructed as a modified version of a phantom devised by the Philips X-Ray Research Laboratories.(12)



a. CAMERA SYSTEM SHOWN WITH B & L f/0.9 LENS



b. CAMERA SYSTEM SHOWN WITH WRAY f/0.71 LENS

Figure 2. Camera, Lens Mount, and Lenses.

Figure 3. Thyr-X Timer and Control Panel.

The phantom consists of plates of Masonite pressed wood (density 1.084 g/cc) 35-cm square arranged in a stack and secured by an adjustable framework of aluminum rods and base plate. The object plate contains 225 holes of varying depth and diameter which will serve as means of determining contrast and resolution. This object plate may be placed in the stack of Masonite sheets, and the number of sheets varied to simulate various thicknesses of the body.

A photograph of the complete phantom is shown in Figure 4.

C. Experimental Procedure

Experimental work this quarter has consisted primarily of test runs of the direct cinefluorographic unit to determine its operating characteristics.

Before operation of the unit, it was believed that the Wray f/0.71 and Bausch and Lomb f/0.9 lenses could be rendered parfocal* with respect to the film plane by visual means. A 7X prismatic magnifier was arranged to view a fine-ground glass screen placed in the film plane. The camera was mounted on an optical bench and the target placed at a distance to conform with the 1:16 image reduction required by the Wray lens. The Wray lens was brought to a sharp visual focus and an index mark was made on the mount (the Wray lens has no focusing scale). The Wray lens was then removed, and the Bausch and Lomb lens substituted with its focusing scale set for the proper target distance. It was then brought to a focus and indexed.

Test runs were made with the cinefluorographic unit using single-frame "still" technique. The film used was Eastman Linagraph Ortho developed in Kodak D-19 developer. A wire-mesh target was used, and examination of the resulting frames showed an inexact focus.

- - - - -

*Parfocal indicates a condition of the mounting such that the focal planes of the two lenses will coincide when interchanged.

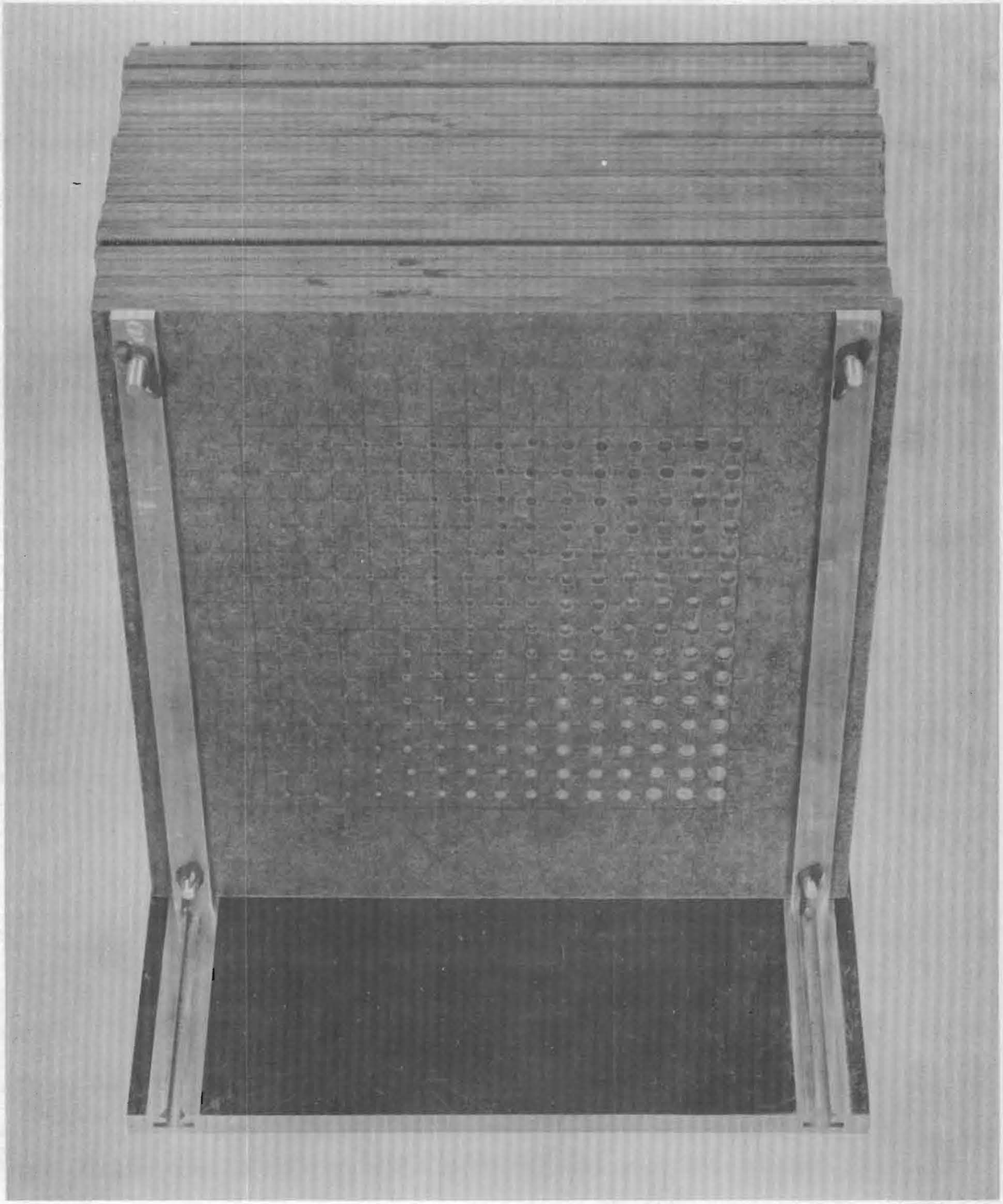
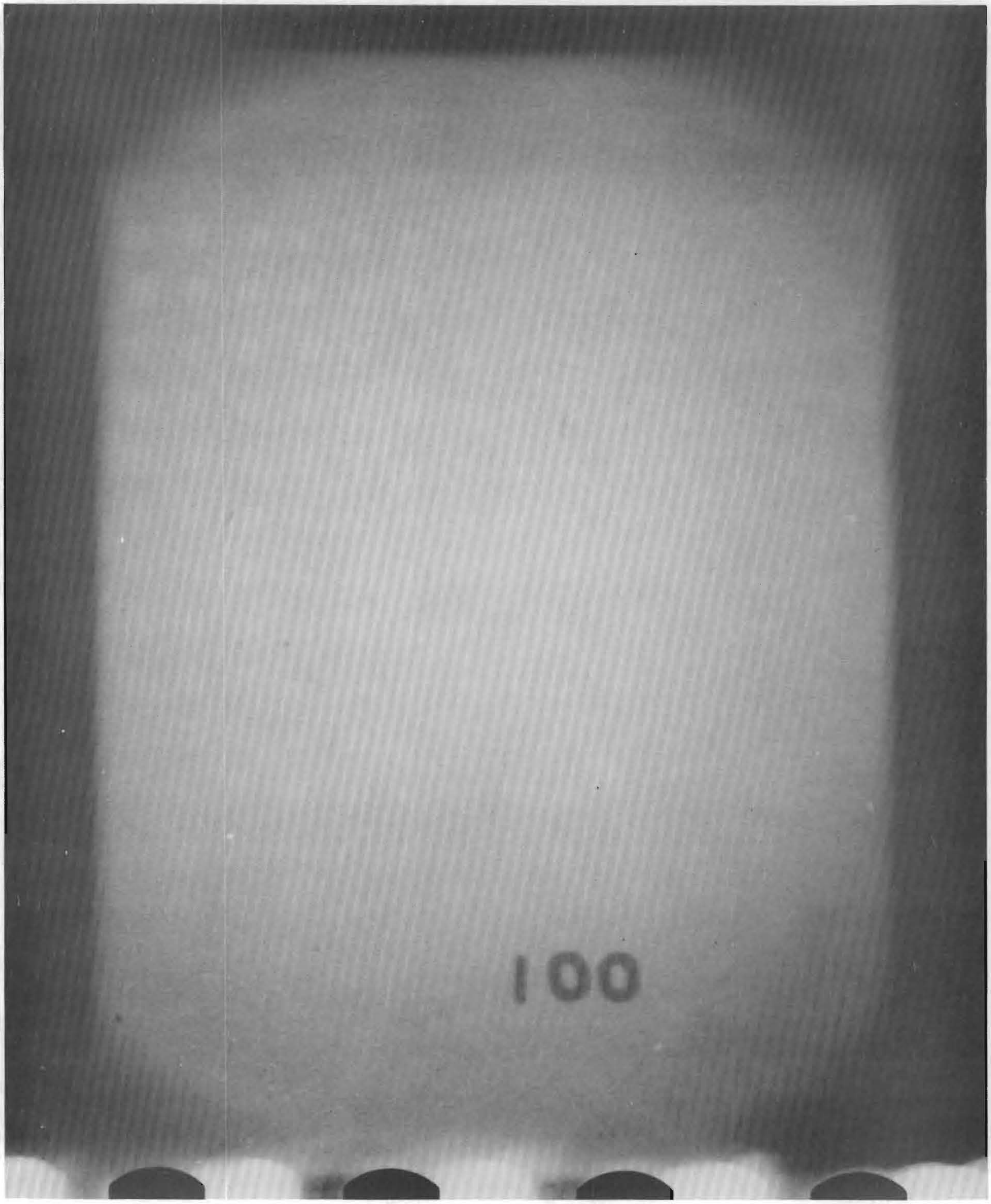


Figure 4. Phantom Assembly.

A focusing scale was then affixed to the Wray lens and a series of exposures made at different focal settings. The point of best focus was then found and marked on the scale.

A fluorographic picture of the phantom is shown in Figure 5. If the picture is examined to determine the holes, which are at the limit of visibility, and if the diameter versus depth of these holes is plotted, a contrast-detail diagram is obtained. Fluorographic pictures of this phantom made under different experimental conditions would yield a family of curves. These curves may then be analyzed to determine the smallest observable volume for a given X-ray technique and cinéfluorographic system.



TEST OBJECT AT CENTER OF 10 cm THICK PHANTOM. EXPOSURE MADE AT 70 KV, 70 ma, 0.5 SEC AT 36" TARGET-SCREEN-DISTANCE.

Figure 5. Fluorographic Image of Phantom.

V. CONCLUSIONS

Since the actual evaluation of systems for electronic cinéfluorography was not begun during the interval being reported, no conclusion directly related to the purpose of the project can be made. However, modification of the nonelectronic cinéfluorographic apparatus has been successful and experimental work has been started.

VI. PROGRAM FOR THE NEXT INTERVAL

For the next interval it is planned to test both the Wray and the Bausch and Lomb lenses for relative speed.

A study will be made of the effect of X-ray source size on resolution. A slit device for resolution measurements will be constructed.

A determination will be made of the effect of X-ray tube voltage on contrast and resolution for various thicknesses of the phantom.

A device to support the image-amplifier assembly, camera and X-ray tube in a relative fixed position is now being designed. It is expected that the design and construction will be completed during the next interval.

VII. PERSONNEL

The personnel working on this project during the period covered by this report are:

Name	Position	Approximate Hours Worked
J. H. Tolan	Project Director	128
J. L. Brown	Assistant Research Physicist	230
J. R. Fields	Technical Assistant	290

Respectfully submitted:

J. H. Tolan
Project Director

J. E. Boyd
Assistant Director

J. L. Brown
Assistant Research Physicist

Paul K. Calaway, Acting Director
Engineering Experiment Station

VIII. BIBLIOGRAPHY

1. Stewart, W. H., Hoffman, W. J., and Ghiselin, F. H., "Cinéfluorography." Am. J. Roentgenol. 38, 465-69 (September 1937).

2. Reynolds, R. J., "Cinéradiography." Am. J. Roentgenol. 33, 522-28 (April 1935).

3. Janker, R., "Roentgen Cinématography." Am. J. Roentgenol. 36, 384-90, (September 1936).

4. Watson, J. S., and Weinberg, S., "A 35-mm Unit for Cinéfluorography." Radiology 51, 728-32 (1948).

5. Ramsey, G. H. S., et al., "Cinéfluorography." Radiology 52, 684-90 (1949).

6. Rushman, R. F., Bark, R. S., and Hendron, J. A., "Clinical Cinéfluorography." Radiology 55, 588-92 (1950).

7. Wynne, C., "A New Form of f/0.71 Lens for 35 mm Ciné-radiography." J. Sci. Inst. 28, 172-73 (1951).

8. Warren, J. C., Weens, H. S., "Hemodynamic Studies Utilizing the Technique of Cinéangiocardiography." U. S. Public Health Service Research Grant No. H-210(c) (A Report). September 1949 to February 1954.

9. Weinberg, S. A., Watson, J. S., and Ramsey, G. H., "X-ray Motion Picture Techniques Employed in Medical Diagnosis and Research." J. of the S.M.P.T.E. 59, 300-08 (October 1952).

10. Weinberg, S. A., Watson, J. S., and Ramsey, G. H., "X-Ray Motion Picture Camera and Printer for 70 mm Film." J. of the S.M.P.T.E. 60, 31-7, (January 1953).

11. Watson, J. S., Weinberg, S., Ramsey, G. H., "A 70 mm Cinéfluorographic Camera and Its Relation to Detail." Radiology 59, 858-65 (December 1952).

12. X-Ray Research and Development, Volume III. N. V. Philips Gloeilampenfabrieken, Eindhoven (Holland), 1937-1950, pp 79-96.

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY REPORT NO. 2

PROJECT NO. A-203

RESEARCH ON ELECTRONIC CINÉFLUOROGRAPHY

- o - o - o - o -

CONTRACT NO. DA-36-039-sc-64615

DEPARTMENT OF THE ARMY PROJECT: 3-99-04-052

SIGNAL CORPS PROJECT: 195B

- o - o - o - o -

AUGUST 31, 1955

PLACED BY THE U. S. ARMY
SIGNAL CORPS ENGINEERING LABORATORIES
FORT MONMOUTH, NEW JERSEY

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY REPORT NO. 2

PROJECT NO. A-203

RESEARCH ON ELECTRONIC CINÉFLUOROGRAPHY

Prepared by

J. H. TOLAN, J. L. BROWN, and R. W. JOHNSON

Object: To determine diagnostic suitability of electronic cinéfluorography

PLACED BY THE U. S. ARMY
SIGNAL CORPS ENGINEERING LABORATORIES
FORT MONMOUTH, NEW JERSEY

MAY 15 to AUGUST 15, 1955

TABLE OF CONTENTS

This Report Contains 23 Pages

LIST OF FIGURES

I. PURPOSE

The purpose of this project is to provide information regarding the suitability of electronic-image-amplification use in cinéfluorography. The project consists of an experimental study of commercially available electronic-image-amplifying devices, which will be used in a system incorporating a motion picture camera for the purpose of recording the image formed on a fluoresecent surface by an X-ray beam.

The work is divided into four principal tasks as follows:

(A) the evaluation of nonelectronic cinéfluorography to obtain basic information on contrast, exposure factors, detail and over-all system efficiency;

(B) the evaluation of electronic cinéfluorography to determine which diagnostic procedures are possible with image amplification and to correlate information obtained in task A;

(C) the fabrication of a laboratory model using an image-amplifying tube; and

(D) the development of accessory items which would be useful in analyzing film results if time and funds permit.

II. ABSTRACT

Comparative resolution and relative speed measurements on the Wray f/0.71 and Bausch and Lomb f/0.9 lenses indicate that the Wray lens is far superior for cinéfluorographic applications. The Wray lens resolved fluorographic images separated by 0.75 mm at the center of the field and separated by 1.0 mm at the edge of the field. The Bausch and Lomb lens resolved images separated by 2.0 mm at the center and was out of focus at the edge of the field. The Wray lens relative speed was somewhat higher than the Bausch and Lomb lens.

Constant-density and contrast-detail curves are included in the report. The constant-density curves indicate the kilovolt and milliampere-second values required to give a resultant film density of 1.0, 1.5, and 2.0 for various phantom thicknesses. The contrast-detail curves show the limit of visibility of the fluorographic image under various operating conditions.

A sequence of film frames taken from a cinéangiocardiogram of a dog is included.

Preliminary results of a test of one type of electronic cinéfluorographic system are given. The over-all amplification of this system as compared to similar results with the nonelectronic system was about 20X.

A description of the special X-ray table designed for this project is included. The completion of this task of the project was delayed by illness of the design engineer.

III. CONFERENCES

On 16 and 17 May 1955, J. L. Brown and J. H. Tolan visited the Eastman Kodak Research Laboratory and the Department of Radiology, University of Rochester Medical School, in Rochester, New York. Characteristics of motion picture film and fluoroscent screens were discussed with Dr. Seemann and Mr. Corney of the Kodak Research Laboratory. This laboratory has conducted some experiments in cinéfluorography using a 16-mm camera and lens system with reasonably good results. Dr. H. S. Weens, Chairman, Department of Radiology, Emory University School of Medicine, and consultant on this project, also participated in the discussions.

Mr. S. Weinberg of the Department of Radiology, University of Rochester Medical School, discussed his experiences with electronic cinéfluorography using the Westinghouse image-amplifier unit and a 35-mm camera and lens system. The opinion expressed was that the 5-inch field size of the image amplifier was a severely limiting factor for all clinical examinations, and the nonelectronic system was the equipment of choice.

The nonelectonic system developed and refined at the University of Rochester is to be made commercially available by the General Electric Company.

Devices for projecting cinéfluorographic film at reduced speed for clinical analysis were discussed with Mr. Weinberg. Using this technique, the group at the University of Rochester has been able to detect significant new clinical findings in a large number of cases from films which had previously been meticulously studied at conventional projection speeds.

IV. FACTUAL DATA

A. Task A. Evaluation of Nonelectonic Cinéfluorography

1. Resolution Measurements

Resolution measurements were made for the cinéfluorographic system using both the Wray f/0.71 and the Bausch and Lomb f/0.9 lenses. A molybdenum slit 0.2-mm wide attached to a micrometer movement and mounted on a stand was arranged to permit the slit to move in the plane of the fluoroscent screen. Successive fluorographic exposures were made after movements of equal intervals at right angles to the long dimension of the slit. This produced a series of equally spaced images of the slit on the film. The resolution was defined as the smallest interval of slit movement which would produce a series of separable images on the film.

Using the Wray lens, the resolution at the center and edge of the camera lens field was 0.75 mm and 1.0 mm, respectively. These measurements were made at the standard 16 to 1 image-reduction ratio specified for the Wray lens.

With the Bausch and Lomb lens it was necessary to make the measurements at a 20 to 1 reduction ratio. Because of the large grain size of the film (Kodak Panchromatic Tri-X), the B & L lens is at a slight disadvantage compared to the Wray lens. The resolution at the center of the lens field was 2 mm. At the edge of the lens field, the image was out of focus. This indicates sufficient curvature of field to limit the use of the Bausch and Lomb lens at 35 mm.

2. Constant-Density Diagrams

Early experiments indicated the desirability of obtaining film exposures of uniform density. This can be accomplished if for a given phantom (or patient) thickness and X-ray tube voltage, the X-ray exposure factor in milliampere-seconds (mas) is known. The exposure factor in mas for D = 1.0, 1.5, and 2.0 can be obtained from the curves in Figures 1, 2, and 3. Each of these graphs represents the operating condition that will produce a particular film density for a given phantom (or patient) thickness.

3. Contrast-Detail Diagrams

Much of the experimental work for this quarter has been devoted to obtaining information for contrast-detail diagrams of the phantom under various operating conditions. A contrast-detail diagram is a plot of diameter versus depth of holes at the limit of visibility in the phantom. From the coordinates of the intersection of the contrast-detail curve with a line representing holes with equal depths and diameters, the minimum detectable volume approximately a sphere (h = d) can be calculated. A comparison of this volume with others under similar operating conditions provides a convenient method of comparing the contrast and detail of the nonelectronic and the electonic cinéfluorographic systems.

The data for the contrast-detail diagrams are obtained by projecting on a white surface the image of the phantom taken on a single film frame. By projecting on a white surface, the enlarged image size was limited by the film graininess rather than the graininess of the screen. The most favorable projection enlargement was found to be 15X. Each film was read by two observers at different times but under the same projection conditions. A comparison of the results showed no significant differences.

Figure 4 shows a family of contrast-detail diagrams plotted from fluorographs of the test plate at various depths in a phantom 10-cm thick. Figure 5 illustrates a family of contrast-detail diagrams at various X-ray tube

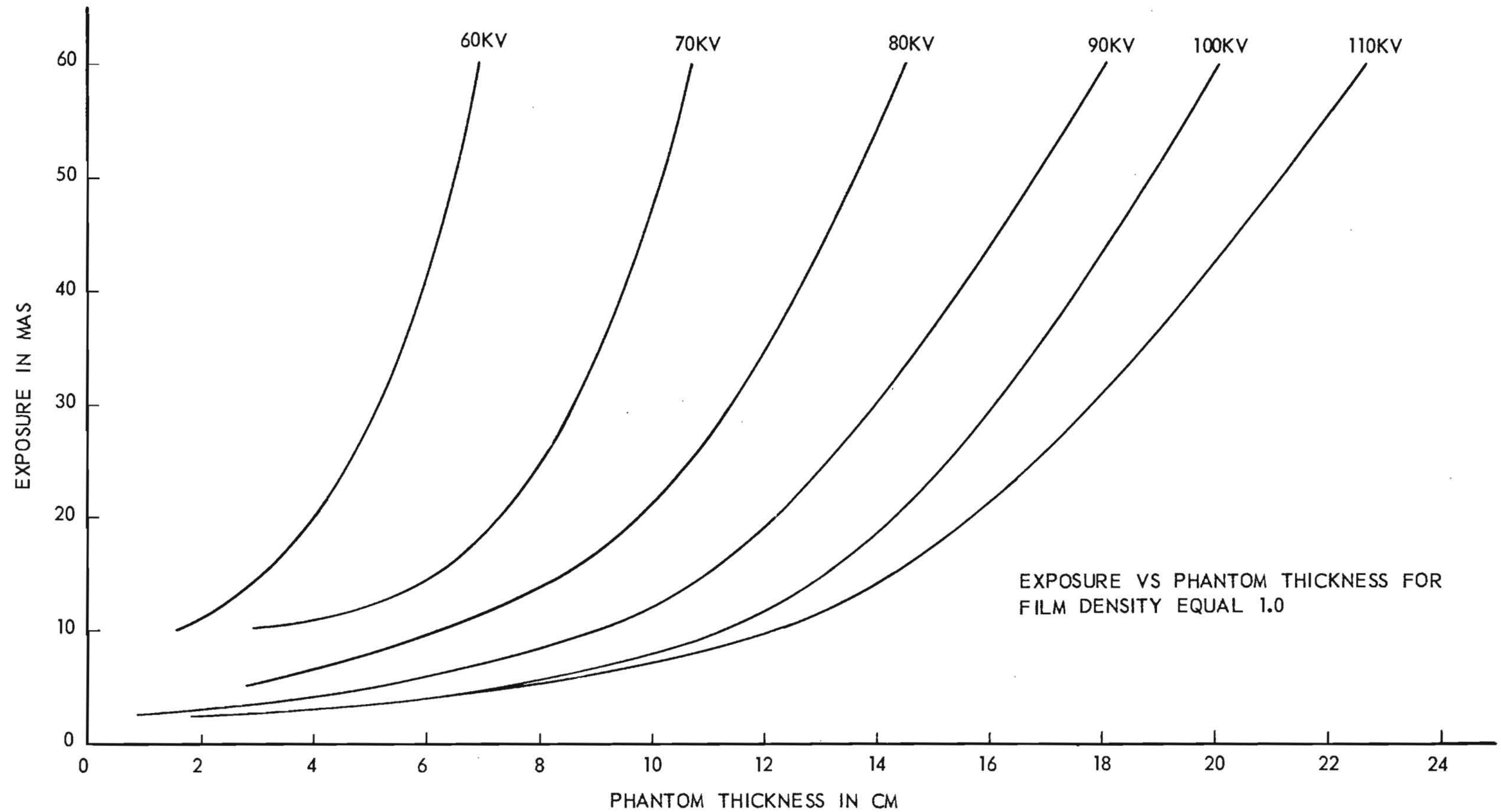


Figure 1. Constant Density Curves for D = 1.0.

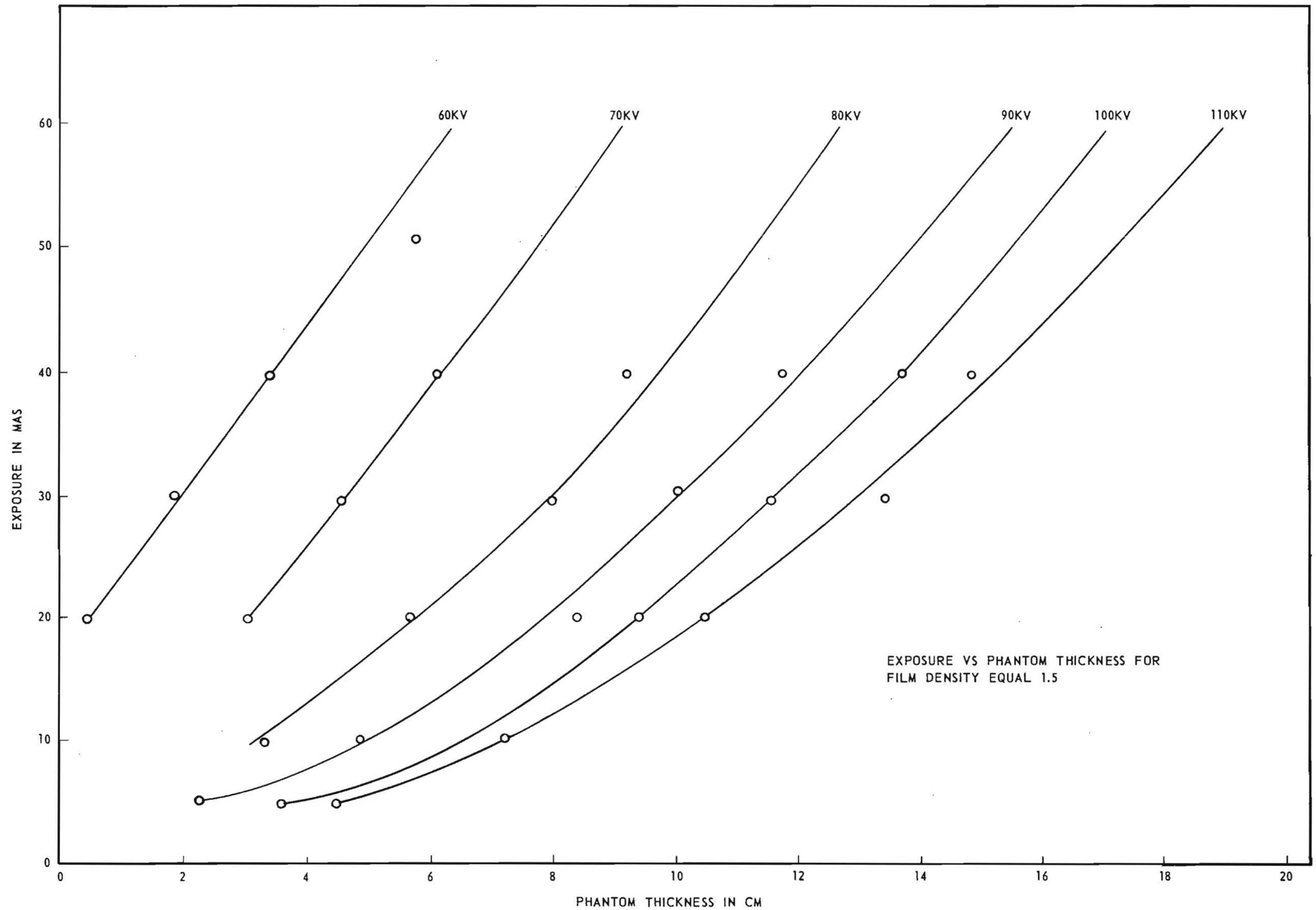


Figure 2. Constant Density Curves for D = 1.5.

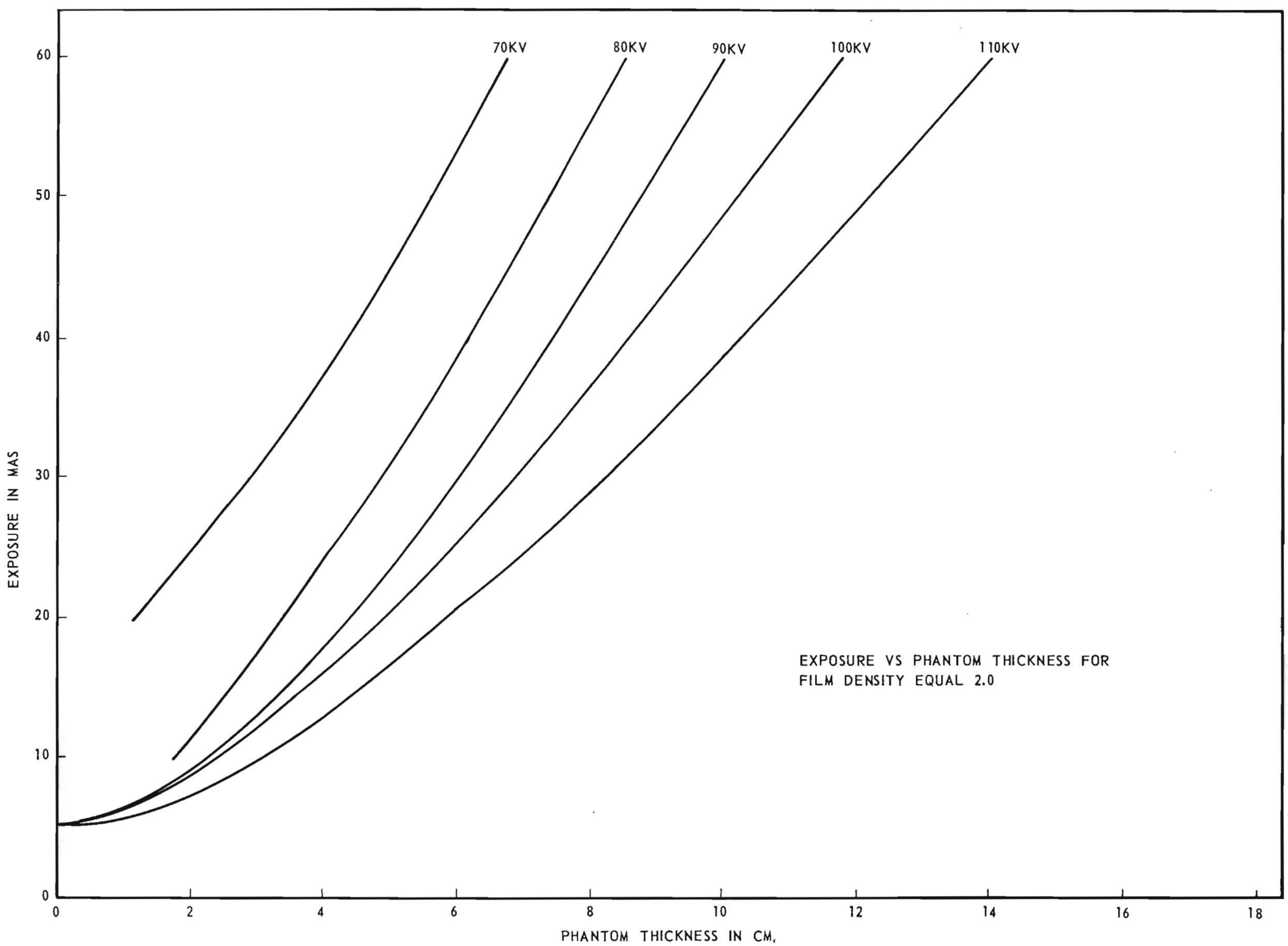


Figure 3. Constant Density Curves for D = 2.0.

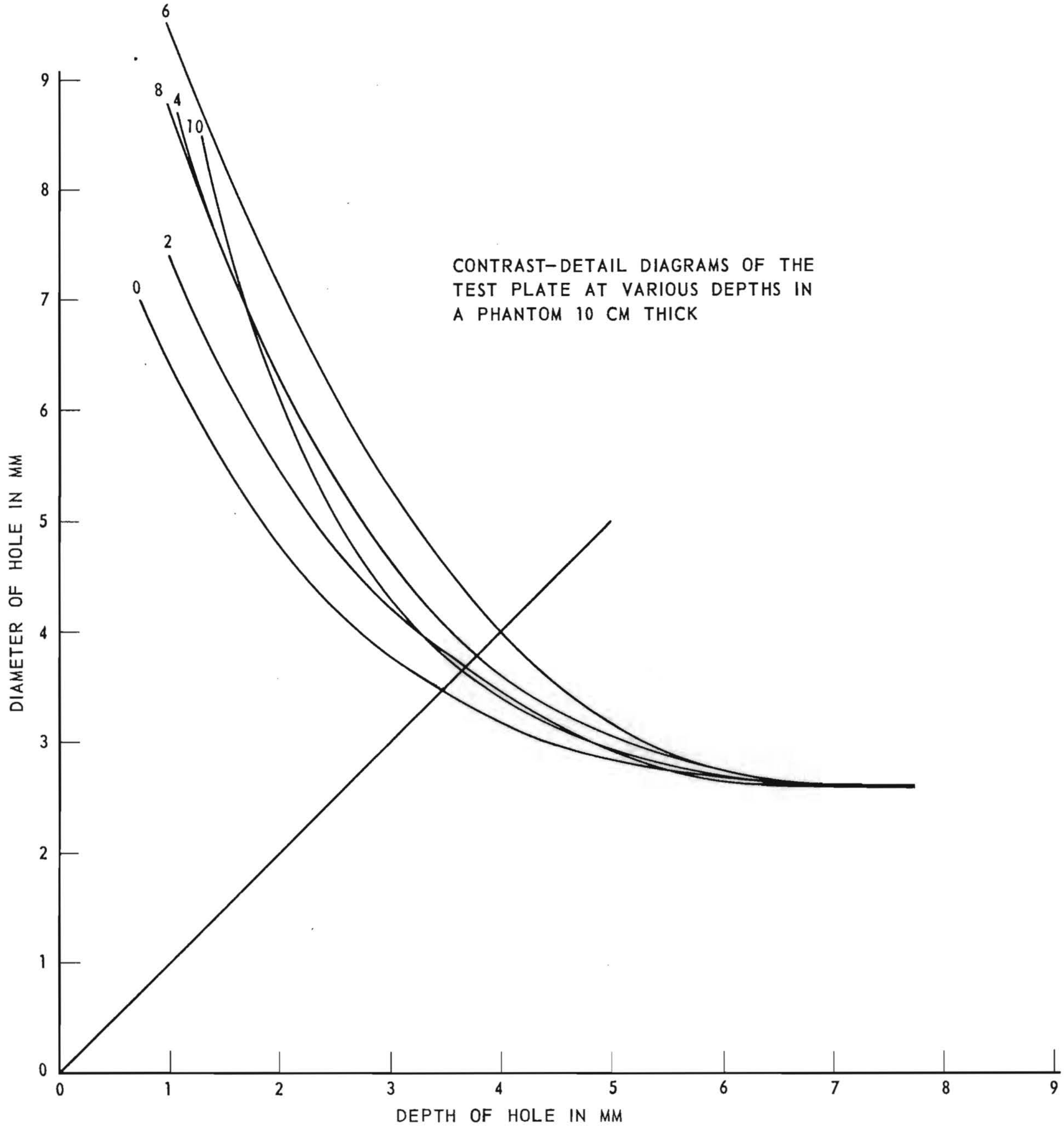


Figure 4. Contrast-Detail Diagram.

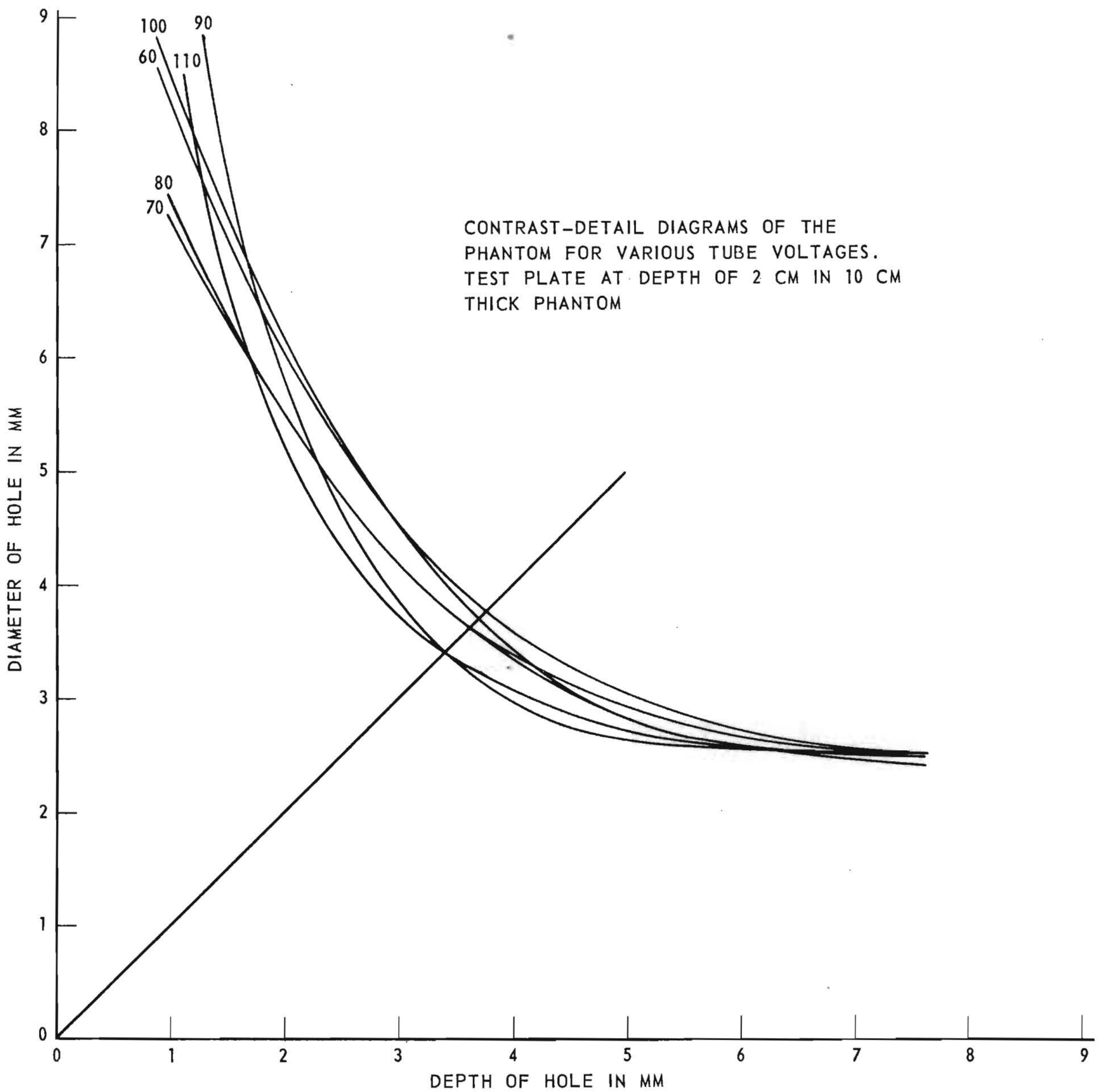


Figure 5. Contrast-Detail Diagram.

voltages with the test plate at a constant depth of 2 cm in a phantom 10-cm thick. The minimum detectable volume for h = d in each case is of the order of 40 mm^3.

Figure 6 illustrates a family of contrast-detail diagrams for various phantom thicknesses between 2.3 and 10.1 cm with the test plate located at the center of the phantom. Figures 7 and 8 show the variations of the contrast-detail diagrams with a constant phantom thickness (2.3 and 10.1 cm) and various X-ray tube voltages. For these two figures, the minimum detectable volumes for h = d are on the order of 16 and 40 mm^3, respectively. This indicates the increase in this volume with increasing phantom thickness.

4. Dog Angiocardiogram

The complete nonelectronic cinéfluorographic system was tested by performing a cinéangiocardiogram on a dog. A series of frames from this film showing the flow of the contrast medium (Diodrast) through the dog's heart are shown in Figure 9.

5. Relative Speed of the Wray and Bausch and Lomb Lenses

The relative speeds of the Wray lens and the Bausch and Lomb lens were determined by taking a series of single-frame fluorographs under identical operating and developing conditions. With a tube voltage of 80 kv and a series of exposures from 0.5 to 5.0 mas, the Wray lens has a slight speed advantage over the Bausch and Lomb lens.

B. Task B. Evaluation of Electronic Cinéfluorography

To begin the experimental work on this task, the Philips image-amplifier tube was setup on an optical bench and coupled to the Bell and Howell "Eyemo" camera for viewing the phantom as shown in Figure 10. The Philips image tube

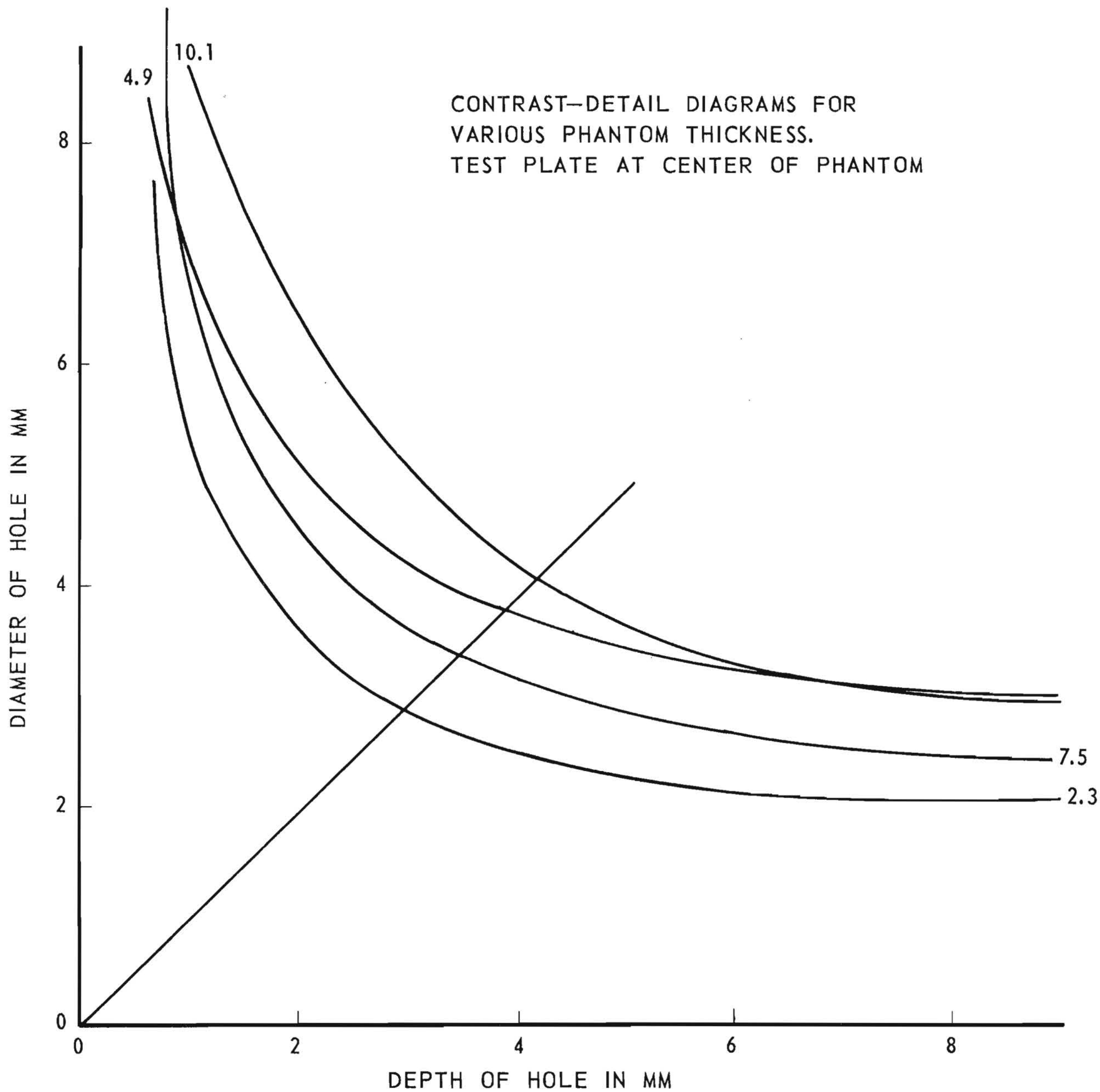


Figure 6. Contrast-Detail Diagram.

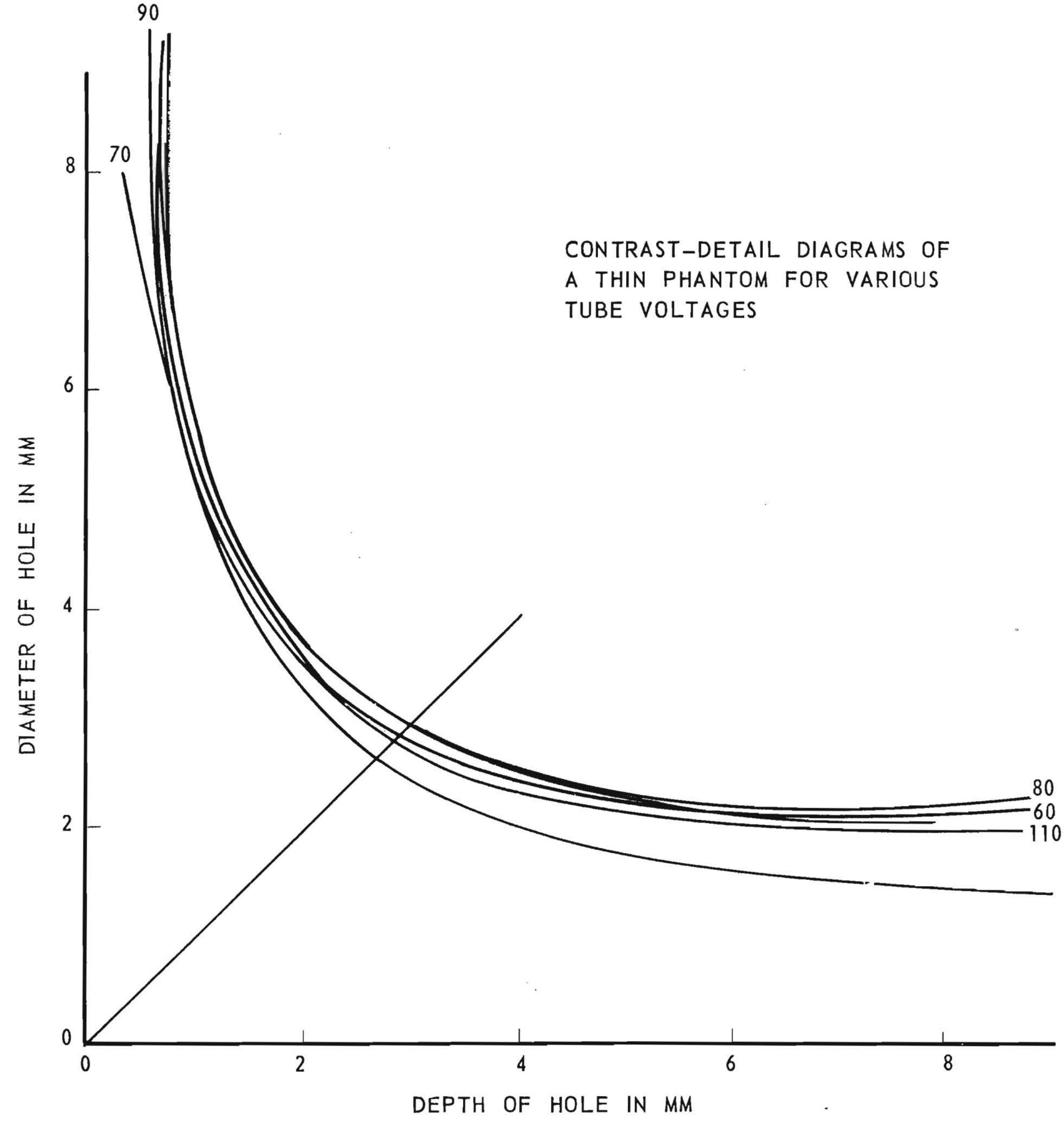


Figure 7. Contrast-Detail Diagram.

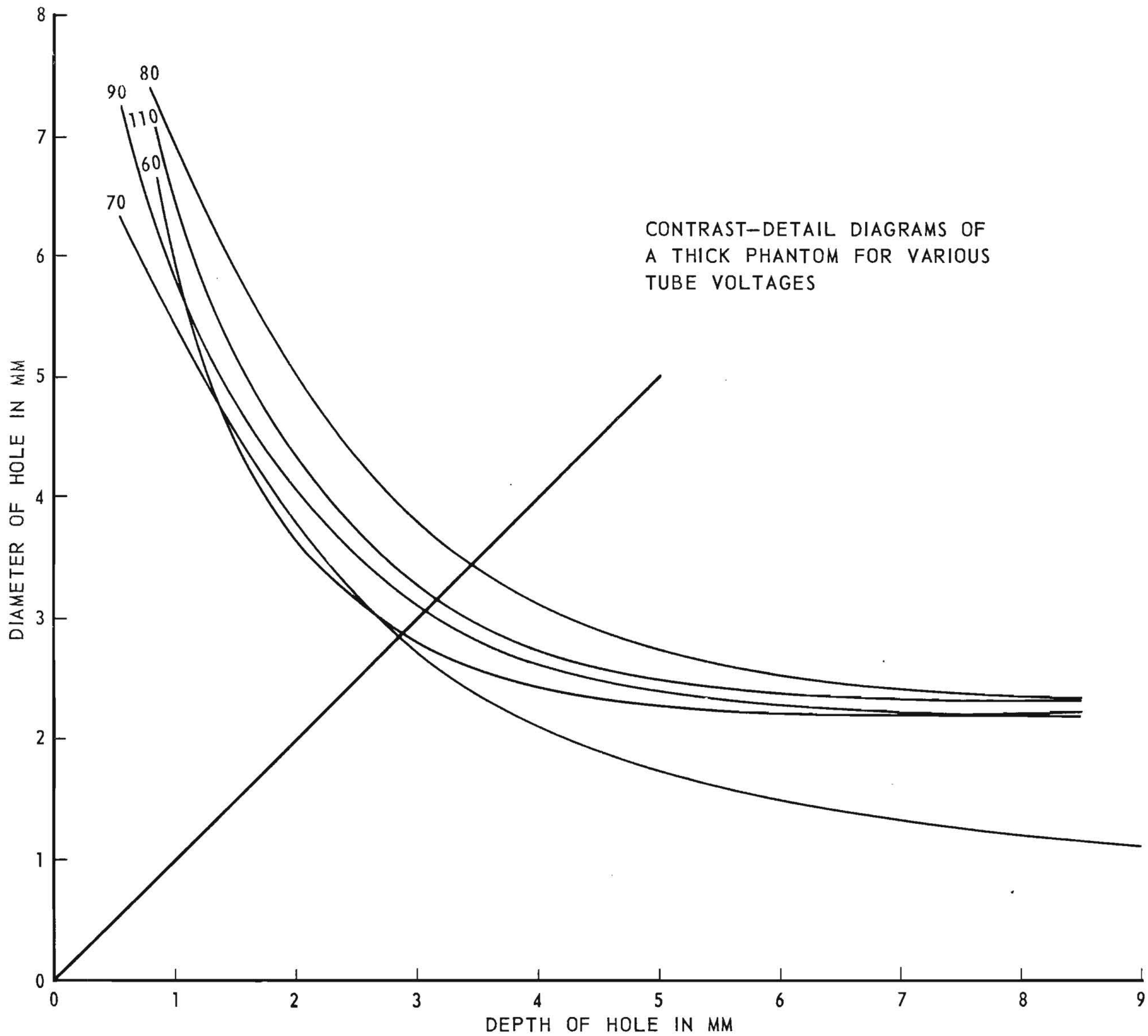


Figure 8. Contrast-Detail Diagram.

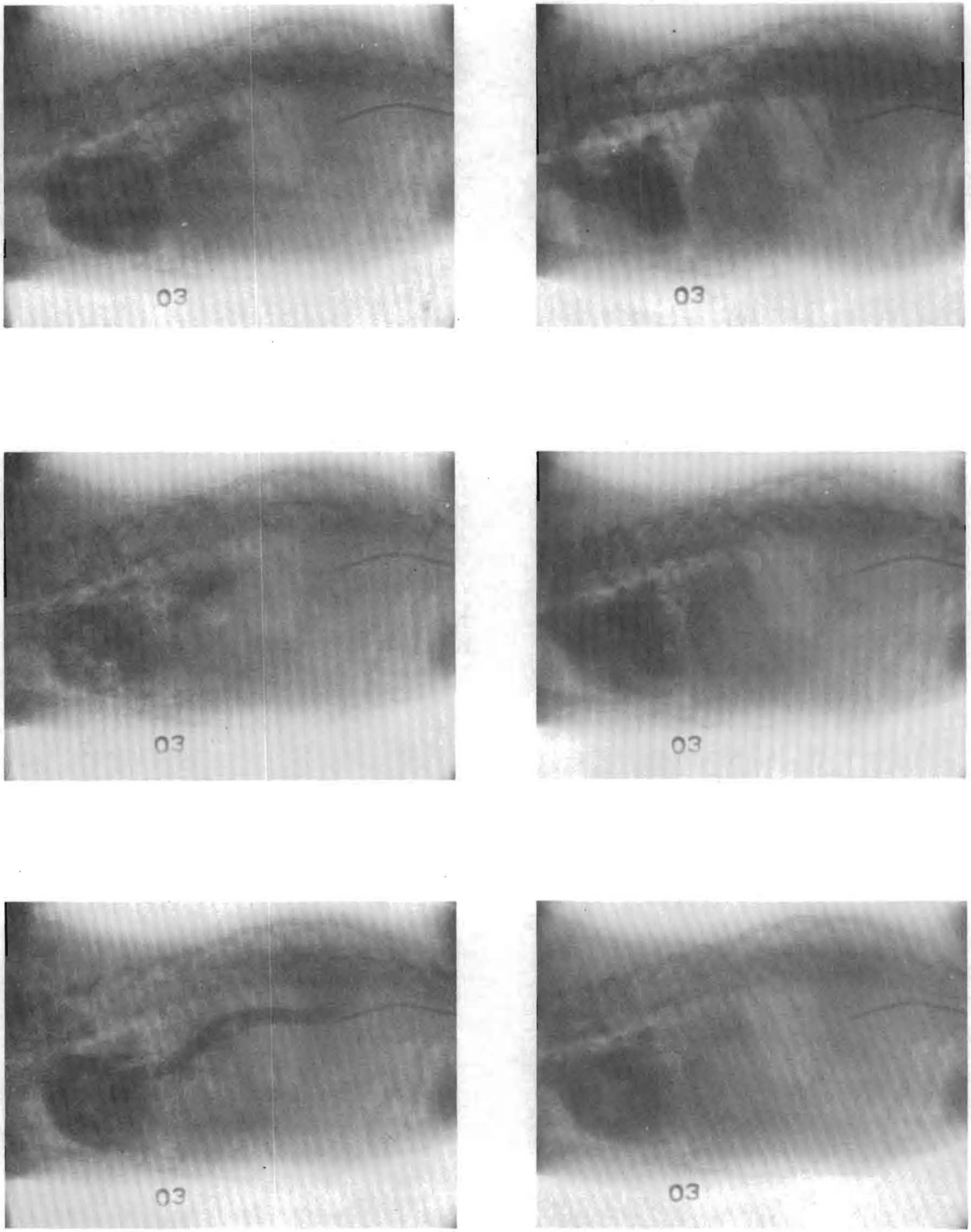


Figure 9. Angiocardiogram of a Dog.

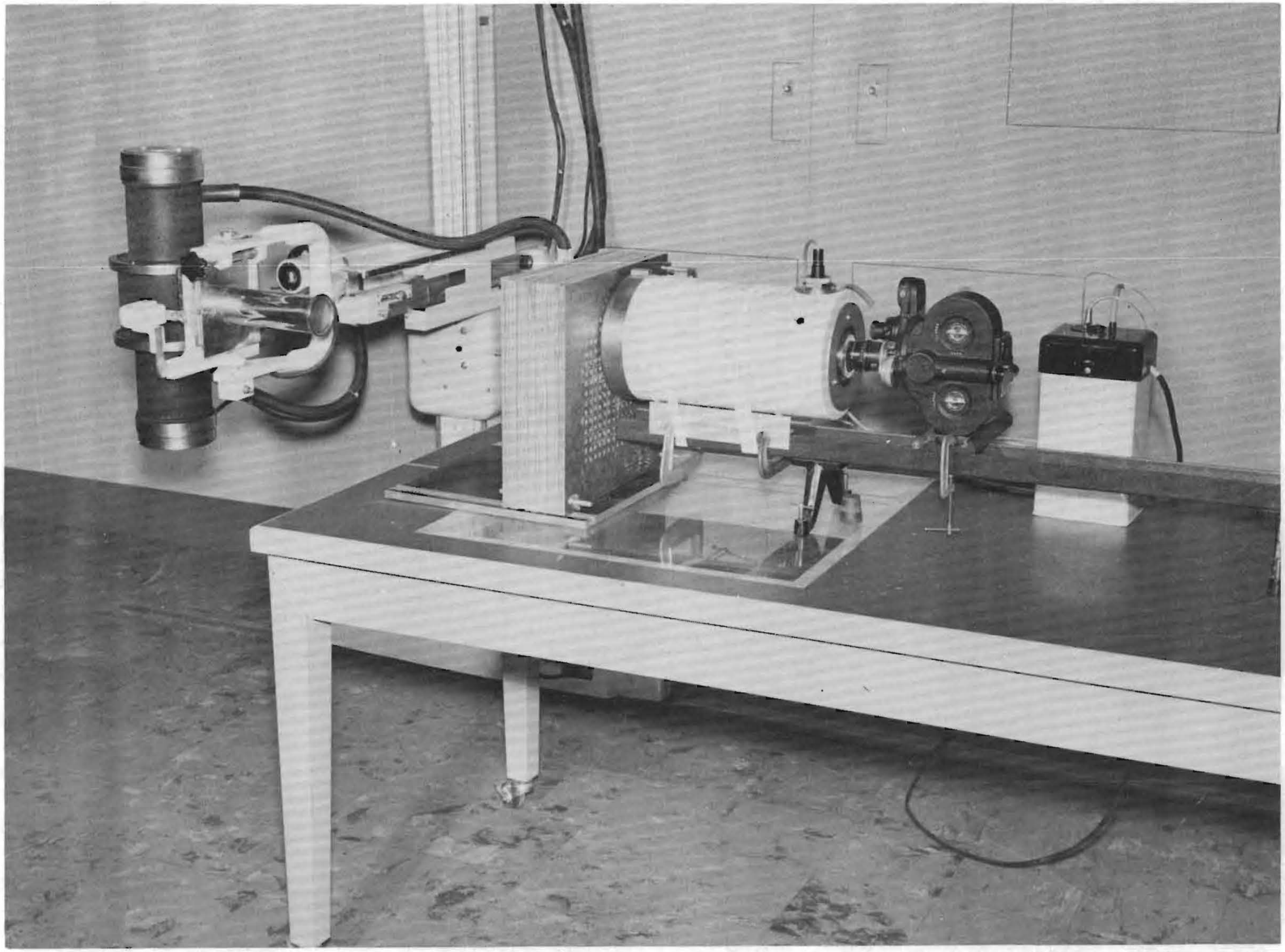


Figure 10. Preliminary Test Arrangement for Philips Image Tube.

is supplied with a 55-mm f/1.5 lens for coupling the output phosphor to the camera system. The lens is positioned with its focal plane coincident with the output phosphor, so that the image formed appears at an infinite distance. The camera lens is then positioned on the axis of the output lens with the camera lens focused at infinity. This focal arrangement favors ordinary camera lenses and tends to yield greater clarity and less distortion in the final image.

The output lens on the Philips tube was originally mounted with a simple slip-clamp fitting. This was considered insufficient for the accuracy required, and a threaded mount was constructed and installed. This mount enables an exact photographic focus to be obtained with the camera lens focused at infinity. This mount will also permit photographic coupling to the output phosphor of the Westinghouse tube.

The camera in use with the image tube is a Bell and Howell "Eyemo" with a f/2.9 lens. Several fluorographs of the phantom have been obtained, but they have not been reproduced for this report. The apparent amplification factor of the Philips image tube is of the order of 5 using the f/2.9 camera lens. With a camera lens of f/1.5, the amplification should increase to about 20.

C. Task C. Fabrication of a Laboratory Model

The clinical evaluation of electronic cinéfluorography requires that a mounting system for the image tube, camera, and X-ray tube be provided such that during the clinical procedure, the assembly may be conveniently moved to follow clinical changes. If the image tube had a larger field of view, this would not be so critical; but with most anatomical parts of interest in the adult human being larger than 5 inches, the assembly must have freedom of movement.

An analysis of this problem indicated the need for a stable, rigid system that was also well balanced and easy to move. Commercial X-ray tables meeting these general requirements are all of recent design and manufacture and are quite expensive. These tables also incorporate features of value in normal radiographic and fluoroscopic procedures, but these features contribute little or nothing to cinéfluorographic procedures.

As a consequence of this analysis, a compromise solution was proposed. If we designed and constructed a special table incorporating our requirements for stability and rigidity but excluding some features of commercial units which would not contribute to this study, we would have a working unit which would more than satisfy the contract technical requirements for a working model and would cost less than a commercial table modified for this use.

In accepting this approach it was not thought that something radically new in table design would evolve. Actually, the resultant design conforms in practically every aspect to commercial practice--as it must since commercial practice is based on accepted clinical techniques which also apply to ciné-fluorography. For example, all results obtained with this unit must be applicable to similar equipment mounted on modern, commercial tables.

The design of the special table is shown in two views in Figure 11. The resemblance to commercial units is immediately apparent.

The expected completion date for this unit has been postponed from that originally contemplated because of a series of unfortunate circumstances. Briefly, these were (1) a spring counterbalance for the tower assembly originally designed into the unit was tested and found unsatisfactory for this application requiring a redesign to dead weight counterbalance and (2) the design

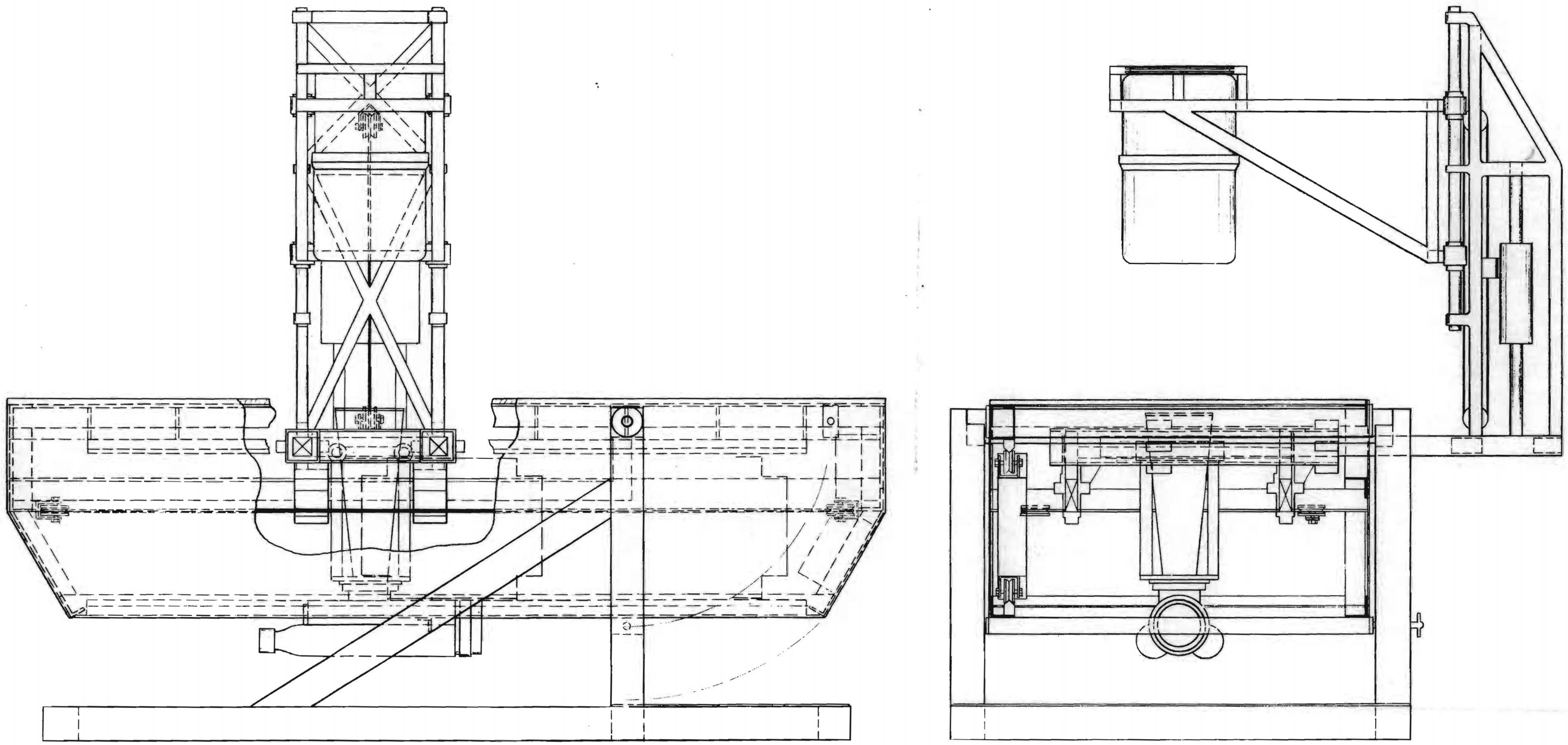


Figure 11. Special X-ray Table.

engineer was ill for several weeks with an undetermined virus infection and all work stopped for that period. These difficulties have been overcome, and the design is now completed. Shop work will begin shortly, and the unit is expected to be in operation during the next interval.

D. Task. D. Other Items of Interest

To assist in the problem of film interpretation, Emory University has purchased a Bell and Howell "Time and Motion Study" projector. This projector will be modified slightly to provide slow-motion projection with minimum flicker and single-frame viewing either forward or reverse. Use of this projector will permit significantly better film interpretation and should prove to be of value in the clinical studies to follow.

V. CONCLUSIONS

A. Task A

Experimental results indicate the present nonelectronic cinéfluorographic apparatus with the Wray f/0.71 lens to be a completely satisfactory unit. Resolution studies and analysis of contrast-detail diagrams have demonstrated the adequacy of the system. This information will serve as one basis of comparison with the electronic systems. Clinical studies to follow will also use the nonelectronic system as a basis of comparison.

B. Task B

Preliminary work with the Philips image tube indicates a relative system amplification of approximately 20X. While this amplification may be somewhat higher than these preliminary results indicate, it is not expected to approach the advertised value of several hundred in this application.

VI. PROGRAM FOR THE NEXT INTERVAL

During the interval, further modifications to the nonelectronic system will be made. These are (1) reduction of the dwell time of the cam-switch assembly that controls the Thyr-X timer so that the cycle of operation of 1/30 sec ON - 1/30 sec OFF is reduced to 1/60 sec ON - 3/60 sec OFF and (2) provision of a second cam-switch assembly to control a synchronizing signal for an electrocardiograph recorder and film-frame marker. The first of these changes is made possible by a new Eastman film which is reported to have twice the speed of the Eastman Linagraph Ortho now in use. The second modification will be made to incorporate in the present system a device developed by the Engineering Experiment Station several years ago for this application but not used for some time.

New test objects of Masonite pressed wood, Plexiglas, and aluminum will be constructed to overcome difficulties encountered with the one in use and to provide new information on materials of higher density.

The special X-ray table will be completed and installed and physical measurements will be initiated. These measurements will be followed by comparative clinical studies but probably not during the next interval.

VII. PERSONNEL

The personnel engaged on this project during the period covered by this report were:

Name	Position	Approximate Hours Worked
J. L. Brown	Assistant Research Physicist	180
J. R. Fields	Technical Assistant	185
R. M. Goodman	Research Engineer	160
R. W. Johnson	Research Assistant	340
J. H. Tolan	Project Director	130

Mr. R. M. Goodman has been working on the design of the special X-ray table and will be associated with the project until this task is completed. As mentioned earlier, the scheduled completion of this table was delayed by Mr. Goodman's illness in July and August.

Mr. J. R. Fields left the project 1 August 1955 to accept an industrial position in Atlanta.

Mr. R. W. Johnson, a graduate student in physics at the Case Institute of Technology, Cleveland, Ohio, was employed for the summer months only and will terminate in September.

Respectfully submitted:

Approved:

J. H. Tolan
Project Director

J. E. Boyd, Head
Physics Division

J. L. Brown
Assistant Research Physicist

Paul K. Calaway, Director
Engineering Experiement Station

R. W. Johnson
Research Assistant

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY REPORT NO. 3

PROJECT NO. A-203

RESEARCH ON ELECTRONIC CINÉFLUOROGRAPHY

- o - o - o - o -

CONTRACT NO. DA-36-039-sc-64615
DEPARTMENT OF THE ARMY PROJECT: 3-99-05-052
SIGNAL CORPS PROJECT: 195B

- o - o - o - o -

NOVEMBER 30, 1955

PLACED BY THE U. S. ARMY
SIGNAL CORPS ENGINEERING LABORATORIES
FORT MONMOUTH, NEW JERSEY

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY REPORT NO. 3

PROJECT NO. A-203

RESEARCH ON ELECTRONIC CINÉFLUOROGRAPHY

PREPARED BY

J. H. TOLAN, J. L. BROWN, A. E. WILLIAMSON,
and W. C. SIMPSON

OBJECT: To determine diagnostic suitability of electronic cinéfluorography

PLACED BY THE U. S. ARMY
SIGNAL CORPS ENGINEERING LABORATORIES
FORT MONMOUTH, NEW JERSEY

AUGUST 15 TO NOVEMBER 15, 1955

TABLE OF CONTENTS

This Report Contains 16 Pages

I. PURPOSE

The purpose of this project is to provide information regarding the suitability of electronic-image-amplification in cinéfluorography. The project consists of an experimental study of commercially available electronic-image-amplifying devices, which will be used in a system incorporating a motion picture camera for recording the image formed on a fluorescent surface by an X-ray beam.

The work is divided into four principal tasks as follows:

(A) the evaluation of nonelectronic cinéfluorography to obtain basic information on contrast, exposure factors, detail and overall system efficiency;

(B) the evaluation of electronic cinéfluorography to determine which diagnostic procedures are possible with image amplification and to correlate information obtained in task A;

(C) the fabrication of a laboratory model using an image-amplifying tube; and

(D) the development of accessory items which would be useful in analyzing film results if time and funds permit.

II. ABSTRACT

Further modifications of the nonelectronic cinéfluorographic system have been completed. The first consisted of a change in the switching system of the Thyr-X timer so that the X-ray beam is ON 1/60 second (one-half the previous time) for each film frame at 15 frames per second. In addition, a signal generator has been incorporated to provide a marker signal for an electrocardiograph recorder and to mark the appropriate film frame simultaneously. This modification permits correlation studies in angiocardiographic examinations.

An electronic cinéfluorographic system incorporating the Philips image-amplifier tube, coupling lenses, and Bell and Howell "Eyemo" camera was set up for a series of animal studies. This system was also used to obtain additional information on the physical characteristics of the Philips tube and to evaluate relative advantages of several motion-picture-film types. The Philips tube being used in this investigation has a persistent central bright spot caused by positive-ion bombardment of the photocathode.

The Westinghouse image-amplifier tube was operated briefly to establish preliminary operational characteristics. The resultant image from this tube has a nonuniform brightness over the image surface. The cause of this defect is not presently known, but the manufacturer advises that the tube be given an extended period of operation to establish if the defect is permanent.

A lens coupling system for the Bell and Howell camera has been devised for both the Westinghouse and Philips tubes utilizing lenses furnished with the Bell and Howell camera. The speed-limiting lens in either setup is a 75 mm, f/2.9 lens. It is assumed that the overall system speed reduction introduced by use of this and other lenses can be calculated. Thus, if the choice of

lenses made on the basis of availability becomes a critical element in the overall system, a better choice of lenses can be recommended.

The fabrication time for the special X-ray table has extended far beyond the original estimate. This has resulted from the general complexity of the choice rather than from production difficulties. However, the final assembly and test is now in progress in the shop. The table will be transferred to its location at Emory University as soon as the final tests are completed.

III. CONFERENCES

There were no conferences attended by project personnel during the report period.

IV. FACTUAL DATA

A. Task A. Evaluation of Nonelectronic Cinéfluorography

The modification of the nonelectronic system providing a shorter X-ray exposure per film frame has been completed. The synchronized switching of the X-ray generator with respect to the camera drive mechanism has been accomplished by triggering the thyratron timer (Liebel-Flarsheim, Thyr-X) with a signal taken directly from the camera drive shaft. A cam driven by the same shaft driving the camera alternately opens and closes a microswitch in the proper sequence so that the X-ray beam is ON only when the film frame is stationary. The sequence previously used provided an X-ray ON time of 1/30 second and an OFF time of 1/30 second for 15-frame-per-second camera speed. A shorter X-ray exposure per film frame would be preferred, but the system as a whole was already operating at its maximum speed.

Eastman Kodak then made available, for experimental use, a Linagraph Ortho film having a special high-speed emulsion. This film was reported to have twice the sensitivity of the conventional Linagraph Ortho, and, if this were indeed the case, the X-ray exposure per film frame could be cut in half. Two choices were thus presented: either (1) increase the framing speed to 30 frames per second with the X-ray beam ON for 1/60 second and OFF 1/60 second or (2) keep the same framing speed and reduce the X-ray ON time to 1/60 second. The latter alternative was selected; since for a given examination, the exposure to the patient would be cut in half.

After the modification was completed, test runs to establish technique factors were made. By comparison with technique factors required for conventional Linagraph Ortho film, the doubled sensitivity of the experimental film was confirmed.

The second modification completed on the nonelectronic system permits the use of an electrocardiograph recorder in conjunction with the cinéfluorographic system. Since the electrocardiograph tracing would have no meaning relative to the film strip unless corresponding positions could be identified, a signal generator has been incorporated in the system which provides a marking signal for the film and the electrocardiograph tracing simultaneously at a frequency of one mark per second. The marking signal is controlled by a separate cam and microswitch driven through a reduction gear by the camera drive shaft, and the marking frequency is controlled by the ratio of the reduction gear. Thus, any desired marking frequency can be obtained by changing the reduction gear ratio.

The modified system was tested with inanimate objects and then successfully used in an angiocardiographic study of a dog.

An omission was made in Quarterly Report No. 2, in the description of technique factors used to obtain the contrast-detail and the constant-density diagrams. Since contrast-detail and film density for a given system depend so critically on the distance between the X-ray target and the fluorescent screen, the distance used in a given experimental situation should be reported with the rest of the significant information. The distance used to obtain the data upon which the curves in Quarterly Report No. 2 were based was 40 inches target-screen-distance.

B. Task B. Evaluation of Electronic Cinéfluorography

Using the experimental arrangement described in Quarterly Report No. 2, several runs were performed with the Philips image-amplifier tube. The first part consisted of preliminary runs on inanimate objects to check lens alignment and focus and X-ray technique factors. The second part consisted of several cinéfluoroscopic examinations of dogs. In each case, the relative intensification of the image compared to similar procedures on the nonelectronic system indicated a factor of intensification higher than the preliminary results noted in Quarterly Report No. 2. This factor of intensification is of the order of a hundred times.

The Philips image-amplifier tube supplied for use on this project had a central bright spot caused by positive-ion bombardment of the photocathode and subsequent secondary electron emission. This bright spot has been relatively constant in intensity since the low mobility of the positive ions creating the spot prevents any variation in this intensity as a function of primary X-ray illumination. Also, since the original ionization does not take place in an isolated region of the tube, the transit time of the positive ions is not constant.

This central bright spot has not prevented the continuance of animal studies, but it has prevented the completion of constant-density and contrast-detail diagrams for the Philips tube. The manufacturer has been notified of this condition, and it is hoped that the tube will be replaced.

The Westinghouse image-amplifier tube was set up in an arrangement similar to that used for the Philips tube. Preliminary films indicate a nonuniform sensitivity of either or both the front and rear phosphor elements. The tube has not been operated for a sufficient length of time to establish this as a permanent or temporary defect.

Using the Philips image-amplifier tube in the experimental studies of animals, several different film types were used to determine the relative advantages of each. In addition to the conventional and experimental Lingagraph Ortho film mentioned previously, Kodak Tri-X and Plus-X films were also used.

C. Task C. Fabrication of a Laboratory Model

1. Design and Construction of Special X-Ray Table

The design of the special X-ray table and virtually all of the fabrication of parts for the table have been completed. Final assembly preliminary to final test has begun in the shop after which the table will be transferred to Emory University. This should be completed during December.

After installing the table at Emory, the X-ray generator and control will be modified to accommodate the new X-ray tube without interfering with the operation of the old X-ray tube. Because this modification will fall just before the Christmas holidays begin, a delay may be experienced in completing the installation.

In making use of this installation, it was considered advantageous to permit examinations of the same patient with either the Philips or Westinghouse image-amplifier tubes. Thus, the table is designed so that the image tubes may be substituted one for the other with a minimum of effort. However, this presents new problems in coupling the output image to the camera. The description of this problem and one solution of the problem are given below.

2. Optical Coupling to Image-Amplifier Tubes

The physical form of presently available image-amplifier tubes poses unusual optical problems in observing or photographing the image obtained with the unit. Both tubes have a 5-inch-diameter input phosphor and either a 1-inch or 0.5-inch output phosphor, and this size reduction introduces an intensity gain factor in addition to that resulting from the electrostatic potentials employed. When the output phosphor is viewed with an optical system magnifying 5 or 10 times, the exact power depending upon the size of the output phosphor, the eye will see a virtual image subtending the same angle as that of the input phosphor when viewed from a distance of approximately 10 inches. Furthermore, if the optical system has an exit pupil with the same diameter as that of the observer's eye when adapted to ambient lighting conditions, the apparent brightness of the output phosphor will be preserved. This is, of course, neglecting losses due to reflection and absorption in the optical system.

For photographing the image on the output phosphor, a different type of system is required. Here, it is required to photograph a small image from a very close distance. Ordinary camera lenses are not designed to work under these conditions since their aberrations are corrected for an object positioned at infinity. In order to make use of standard photographic lenses, two lens systems in tandem must be used. One system is placed with its focal plane located in the plane of the output phosphor, so that the rays from any point in the image plane emerge in a parallel beam. The second lens system is placed on the axis of the first lens and accepts the parallel beam from this lens. The final image is formed by the second lens in the plane of the film. If the coupling lens and taking lens have equal focal lengths, the final image will be the same size as the object. However, it is possible to vary the size of the final image. If f_1 is the focal length of the coupling lens and f_2 that of the taking lens, then the image-size-amplification factor will be given by the ratio f_2/f_1.

As mentioned previously, the two available amplifier tubes have output phosphors of approximately 0.5-inch and 1-inch diameter respectively. Since the characteristics of these tubes are to be compared, a desirable optical system would produce the same image size for both tubes. Furthermore, the desirable size for a final image in relation to the standard 35-mm ciné frame is neither 0.5 inch nor 1 inch. Satisfying these specifications with standard focal-length lenses is difficult.

One such coupling system has been worked out for use on this project. Since the Philips intensifier tube comes equipped with a 55-mm, f/1.5 coupling lens, it was considered desirable to use this as the base of the optical system. When this tube and lens are used with a 75-mm taking lens, the final image size is approximately 18 mm. If this same 75-mm lens is then used as a coupling lens on the Westinghouse tube, and if a 50-mm lens is used as the taking lens, the final image size is about 17.5 mm. The 75-mm lens was furnished by the Signal Corps for use with the "Eyemo" camera. It has a maximum focal ratio of f/2.9, and, consequently, serves as the limiting lens with respect to photographic speed on both the Westinghouse and Philips systems since it is the slowest lens in the system. A more desirable system would utilize a faster 75-mm lens, but this is a rather expensive item.

D. Task D. Other Items of Interest

Because of the effort in personnel time and materials required to design and construct the special X-ray table, further consideration of other items of interest had to be dropped. It is hoped that a renewal contract can be awarded so that this aspect of the study may be continued.

V. CONCLUSIONS

A. Task A

The modified nonelectronic system has been successfully used in animal cinéangiocardiography. The synchronization of the electrocardiograph record with the X-ray film record makes possible the detailed analysis of the heart action during experiments. The use of the Kodak experimental Linagraph Ortho film reduces by a factor of two the X-ray exposure to the patient.

B. Task B

The electronic cinéfluorographic system using the Philips tube, operated under conditions similar to those above, showed an image intensification of approximately 100 to 1. However, the resultant film had much better resolution than the resultant film for the nonelectronic system. This is probably due to a combination of two factors: the brighter image provided by the amplifier tube and the finer grain film (Kodak Plus-X). The bright spot in the center of the output phosphor has made precise evaluation of the film records impossible.

VI. PROGRAM FOR THE NEXT INTERVAL

After completing the installation of the special X-ray table, the operational characteristics of the image-amplifying tubes will be studied and compared with the earlier results from the nonelectronic system. Following these measurements, a limited clinical program will be started. The medical staff of Emory University has demonstrated an increasing interest in the use of cinéfluorographic techniques, and many clinical problems have been suggested for study. It is hoped that the more important of these can be included before the termination of the contract.

VII. PERSONNEL

The personnel engaged on this project during the period covered by this report were:

Name	Position	Approximate Hours Worked
J. L. Brown	Assistant Research Physicist	195
R. M. Goodman	Research Engineer	130
R. W. Johnson	Research Assistant	135
W. C. Simpson	Research Associate	130
J. H. Tolan	Project Director	130
A. E. Williamson	Research Physicist	270
H. D. Youmans	Research Assistant	260

Dr. Simpson became associated with the project in September and acted as a consultant on the optical and photographic problems. A biographical sketch is attached in the appendix.

Mr. Williamson joined the staff of the Engineering Experiment Station in September and was assigned part-time to the project. He has assisted Mr. Tolan in the overall aspects of the project. A biographical sketch for Mr. Williamson is also included in the appendix.

Respectfully submitted:

J. H. Tolan
Project Director

J. L. Brown
Assistant Research Physicist

A. E. Williamson
Research Physicist

W. C. Simpson
Research Associate

Approved:

J. E. Boyd
Chief, Physical Sciences Division

Paul K. Calaway, Director
Engineering Experiment Station

VIII. APPENDIX

BIOGRAPHICAL SKETCH

SIMPSON, William C.

Rank: Assistant Professor of Physics and Research Associate, Engineering Experiment Station, Georgia Institute of Technology

Education:

A.B., Physics, Mercer University	1947
M.S., Physics, University of Kentucky	1949
Ph.D., Physics, University of Virginia	1955

Experience:

1. U. S. Navy, Communications Officer	1943-45
2. Mercer University, Macon, Georgia Physics Department	
1. Laboratory Instructor (Part Time)	1946-47
3. University of Kentucky Physics Department	
2. Graduate Assistant	1947-49
3. Instructor (Part Time)	1949
4. Georgia Institute of Technology, Physics Dept. Instructor of Physics	1949-51
5. U. S. Navy, Communications Officer and First Lieutenant	1951-53
6. University of Virginia Physics Department	
1. Teaching Assistant	1953-54
2. Eastman Kodak Fellow	1954-55
3. Assistant Professor (Part Time)	1955
7. Georgia Institute of Technology	
1. Assistant Professor of Physics	1955-date
2. Research Associate, E.E.S.	1955-date

Ph.D. Dissertation:
"Determination of Molecular Weights by Equilibrium Ultracentrifuge Method"

Fields of Special Interest:
Classical Mechanics, Thermodynamics, Geometrical and Physical Optics, High Centrifugal Fields and Bio-Physics

WILLIAMSON, Arthur Eldridge, Jr.

Rank: Research Physicist, Engineering Experiment Station, Georgia Institute of Technology

Education:

B.S., Engineering Physics, Alabama Polytechnic Institute	1950
M.S., Physics, Alabama Polytechnic Institute	1951
Graduate Study, UCLA	1952

Experience:

1. U. S. Navy, Aviation Radio and Radar Operator	1944-46
2. Alabama Polytechnic Institute Department of Physics 1. Laboratory Instructor (Part Time) 2. Teaching and Research Assistant	 1948-50 1950-51
3. Air Proving Ground, Eglin AFB, Florida Photographic Engineer	 1950
4. North American Aviation, Inc. Aerophysics and Atomic Energy Laboratory Research Engineer	 1951-52
5. University of Richmond Department of Physics Instructor in Physics	 1952-53
6. Southern Research Institute Physicist	 1953-55
7. Georgia Institute of Technology Engineering Experiment Station Research Physicist	 1955-date

Publications:

Several papers and reports in classified journals and documents related to fields of electromechanical engineering, spectrophotometry and studies of aerosols.

Fields of Special Interest:

Particle Physics, Electromechanical Engineering, Acoustics and Spectrophotometry

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY REPORT NO. 4

PROJECT NO. A-203

RESEARCH ON ELECTRONIC CINEFLUOROGRAPHY

- o - o - o - o -

CONTRACT NO. DA-36-039-sc-64615
DEPARTMENT OF THE ARMY PROJECT NO. 3-99-05-052
SIGNAL CORPS PROJECT NO. 195B

- o - o - o - o -

MARCH 15, 1956

PLACED BY THE U. S. ARMY
SIGNAL CORPS ENGINEERING LABORATORIES
FORT MONMOUTH, NEW JERSEY

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY REPORT NO. 4

PROJECT NO. A-203

RESEARCH ON ELECTRONIC CINEFLUOROGRAPHY

By

J. H. TOLAN, A. E. WILLIAMSON
and W. C. SIMPSON

OBJECT: To determine diagnostic suitability of electronic cinefluorography.

PLACED BY THE U. S. ARMY
SIGNAL CORPS ENGINEERING LABORATORIES
FORT MONMOUTH, NEW JERSEY

NOVEMBER 15, 1955 to FEBRUARY 15, 1956

TABLE OF CONTENTS

This report contains 12 pages.

LIST OF FIGURES

I. PURPOSE

The purpose of this project is to provide information regarding the suitability of electronic-image-amplification in cinéfluorography. The project consists of an experimental study of commercially available electronic-image-amplifying devices, which will be used in a system incorporating a motion picture camera for recording the image formed on a fluorescent surface by an X-ray beam.

The work is divided into four principal tasks as follows:

(A) the evaluation of nonelectronic cinéfluorography to obtain basic information on contrast, exposure factors, detail and overall system efficiency;

(B) the evaluation of electronic cinéfluorography to determine which diagnostic procedures are possible with image amplification and to correlate information obtained in Task A;

(C) the fabrication of a laboratory model using an image-amplifying tube; and

(D) the development of accessory items which would be useful in analyzing film results if time and funds permit.

II. ABSTRACT

Results of a study of different film emulsions indicate that, in general, several film types can be used for cinéfluorography. The choice of a suitable film would be determined by a compromise between the amount of X-ray exposure which can be tolerated and the resolution required. To standardize the processing of film, the Eastman Kodak Special Linagraph Ortho will be used in the experimental program.

Preliminary technique curves for the Westinghouse and Philips electronic systems are reported. These curves represent the best effort that could be made to resolve irregularities in the output characteristics of both tubes; and consequently, the curves should not be interpreted as conclusive.

The special X-ray table has been installed and found to operate satisfactorily. Several minor modifications to facilitate its use are planned.

III. CONFERENCES

There were no conferences attended by project personnel during the report period.

IV. FACTUAL DATA

A. Task B. Evaluation of Electronic Cinéfluorography

Thus far, the experimental work on this project has involved the investigation of several variable factors which contribute to the diagnostic value of a fluorographic image. The purpose of this report is to summarize this work, giving preliminary results of the system comparisons, and to outline briefly the further determinations to be made under a contract extension.

Among the several different film emulsions used were Kodak Tri-X, Kodak Plus-X, Eastman Linagraph Ortho, Eastman Special Linagraph Ortho Emulsion No. 0-1130-2-01 and DuPont High Speed Panchromatic Emulsion No. SX 246-010-7. From the work which has been done, no one film can be said to be best for cinéfluorography. For example, use of Plus-X film gives much better resolution than the other films but requires an X-ray exposure several times the exposure required by the other films. In order to further evaluate the systems it is proposed that only one film, the Eastman Special Linagraph Ortho, be used. In a case where finer detail is required, Plus-X film can be used.

All of the film was developed in type-X positive developer to obtain the high contrast desirable in a fluorographic image.

Film processing for this project has been done by the Motion Picture Unit of the U. S. Public Health Service's Communicable Disease Center at Chamblee, Georgia. This organization has 16mm and 35mm developing machines and 35 to 16mm printers. Their service has been made available without charge. It is believed that this type of developing procedure is more standardized than any which could be devised on a small-batch basis.

Preliminary technique curves for the two electronic systems are shown in Figures 1 and 2. Some of these data were taken with other film types, but it has all been reduced to the equivalent value for the Eastman special film by comparison of optical density-versus-MAS data for each film. Note that each curve is for a complete system (containing an X-ray-to-optical conversion device, lenses and camera). These two systems will be discussed below.

The electronic system utilizing the Westinghouse image-amplifier tube consists of the following: a Westinghouse image-amplifier tube (serial no. 313095), a coupling lens (75mm, f/2.9), a camera lens (50mm, f/2.8) and a Bell and Howell "Eyemo" camera with a 160° (open) shutter operating at 16 frames per second. As mentioned in earlier reports, the Westinghouse tube has an output which is not uniform over the face of the screen. Correspondence with the manufacturer indicates that they are in agreement with our results since a film which they exposed on final test of the tube shows identical nonuniformity. Unfortunately, this variation is considered within specifications and has been passed routinely by their quality control department. Their letter mentions, however, that Westinghouse is considering establishing new specifications for an intensifier to be used in

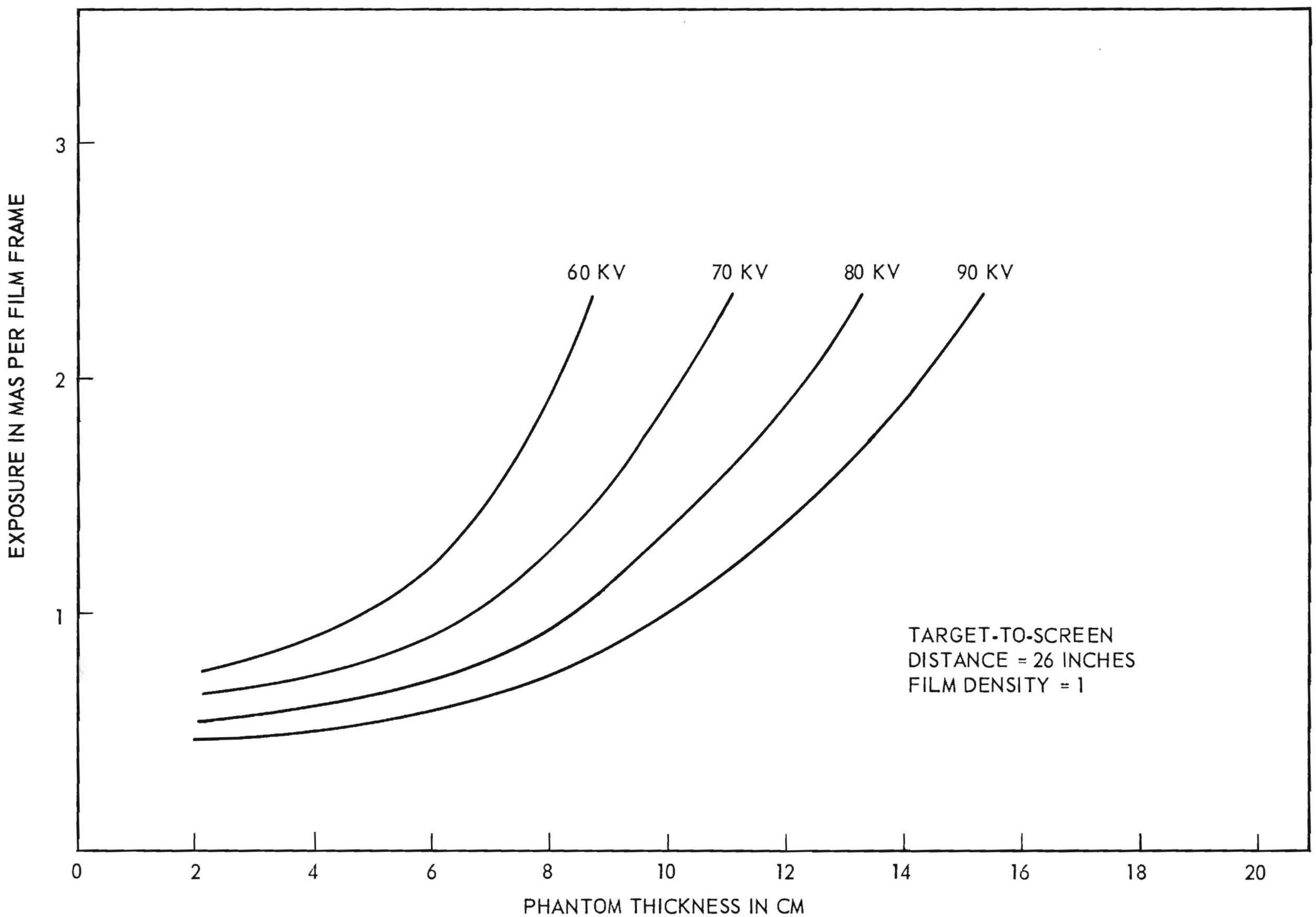


Figure 1. Preliminary Technique Curve for the Philips Image-Amplifier Tube System.

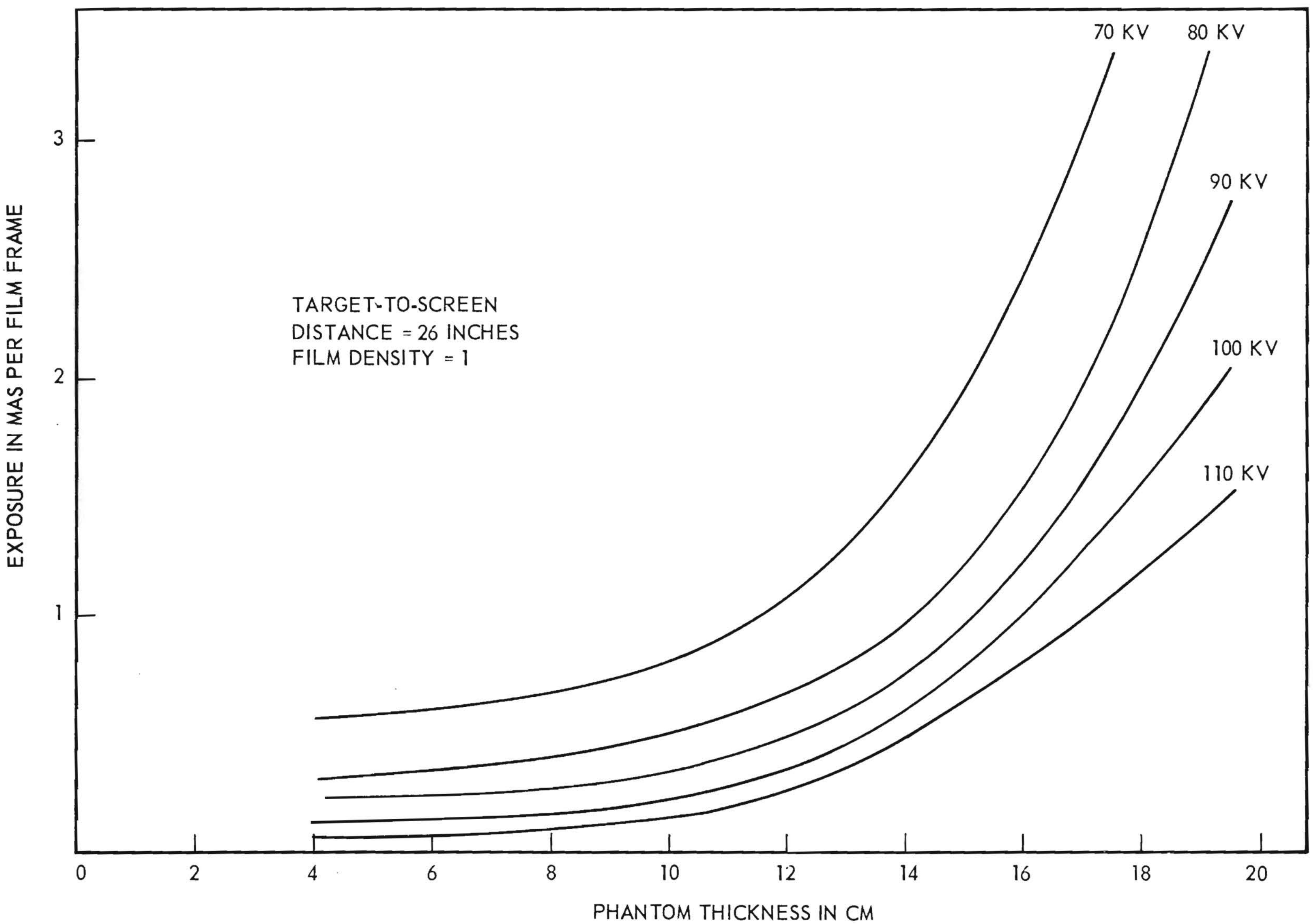


Figure 2. Preliminary Technique Curve for the Westinghouse Image-Amplifier Tube System.

cine applications. This will be a tube which has been selected for its uniform output and will be sold at a higher price.

Because of this variation of intensity across the output phosphor, there is the possibility of large-scale errors in reading the density from film taken with this tube. Also, as the intensity varies across the tube, the technique shown is applicable only to the area of the tube face where these measurements were made and, therefore, represents no more than an average value for the total area of the tube face.

The electronic system utilizing the Philips image-amplifier consists of the following components: a Philips image-amplifier, a coupling lens (55mm, f/1.5), a camera lens (75mm, f/2.9) and the Bell and Howell "Eyemo" camera operated as described above. This particular Philips tube has a bright spot at the center of the output phosphor. This fault limited the usefulness of the tube and measurements made are also subject to error. Correspondence with the manufacturer determined the fault to be due to positive ion bombardment of the photocathode. These positive ions are formed from residual gases in the tube and are focused by the electrostatic lenses on the center of the photocathode where they emit secondary electrons producing a like image on the output phosphor. The manufacturer accepted responsibility for the defect and agreed to replace the tube.

Figures 1 and 2 represent the bulk of the experimental determinations to date. As pointed out previously, the curves for the two electronic systems represent compromises because of the nonuniformity of the output phosphor of the two intensifiers. With the receipt of a more satisfactory Philips tube, it will be possible to obtain more reliable data on that tube.

Figure 3 shows a series of exposures made with all three systems on the two film types. The exposures for the two electronic systems clearly show the defects mentioned above. The relative speed of the two film types is not apparent from this illustration but densitrometric measurements indicate the Eastman Special Linagraph Ortho film to be slightly faster, in this application, than the DuPont Special Panchromatic film.

B. Task C. Fabrication of a Laboratory Model

The installation of a special X-ray table described in previous reports has been completed. This table with the Westinghouse image-amplifier tube, "Eyemo" camera and suitable coupling lenses were used in the initial installation. Preliminary results with the use of the Westinghouse tube were unsatisfactory, as previously described, but the operation permitted an evaluation of the operation of the table and of the Westinghouse tube.

The table was designed to be used in two fixed orientations. The first, and perhaps more common, is that shown in Figure 4 with the table in a horizontal position, the X-ray tube under the table and the amplifier tube and camera assembly over the table. The second position, shown in Figure 5, has the table inclined vertically with the X-ray tube behind and the image tube and camera assembly in front of the system.

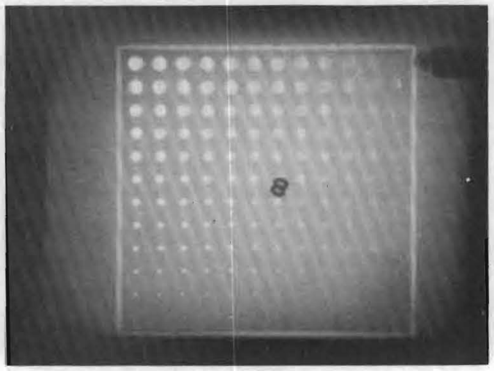
Use of this system has indicated the need for several minor refinements which will be undertaken during the next period. The use of the table, however, has not been restricted by these factors, and a clinical study of normal and pathological laryngeal function has been started.

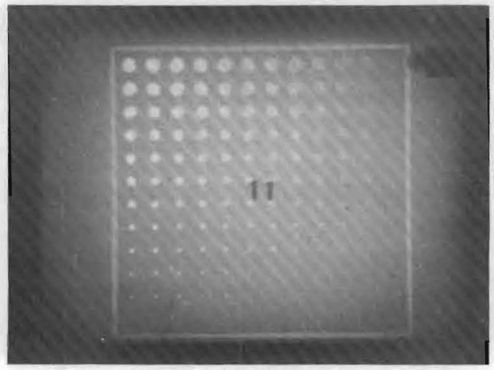
A mounting system for the Philips image-amplifier tube has not been fabricated since the tube is to be replaced and a new one was not available before the end

ALUMINUM TEST OBJECT IN 10 CM MASONITE PHANTOM

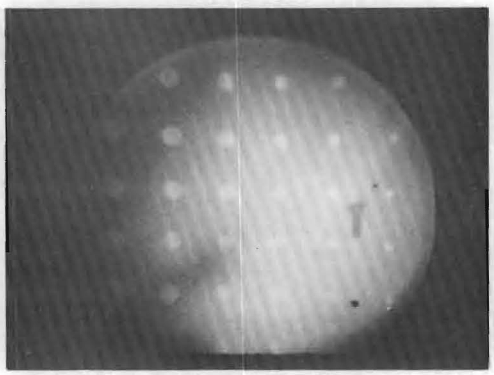
EASTMAN SPECIAL
LINAGRAPH ORTHO

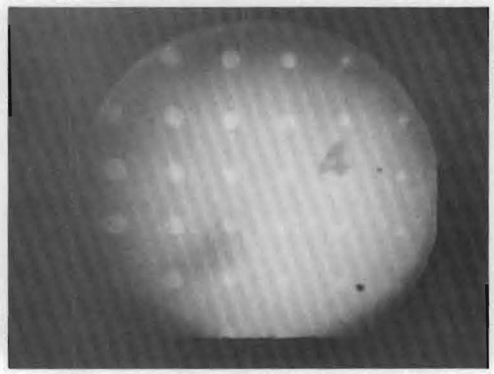
DUPONT SPECIAL
PANCHROMATIC



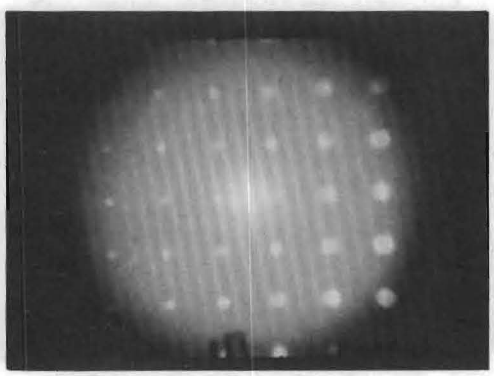


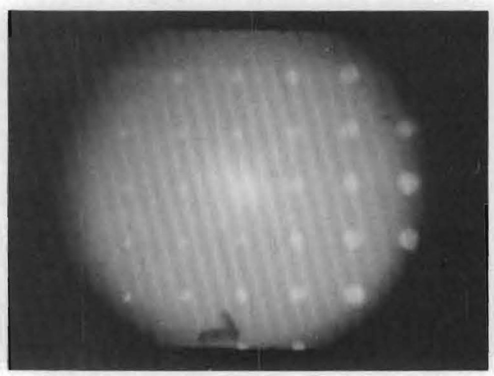
NONELECTRONIC, 105 KVP, 130 MA, 1/60 SEC. EXPOSURE AT 15 FRAMES/SEC.





WESTINGHOUSE, 70 KVP, 30 MA, 1/36 SEC. EXPOSURE AT 16 FRAMES/SEC.





PHILIPS, 50 KVP, 30 MA, 1/36 SEC. EXPOSURE AT 16 FRAMES/SEC.

Figure 3. Film Exposure with Cinéfluorographic Systems.

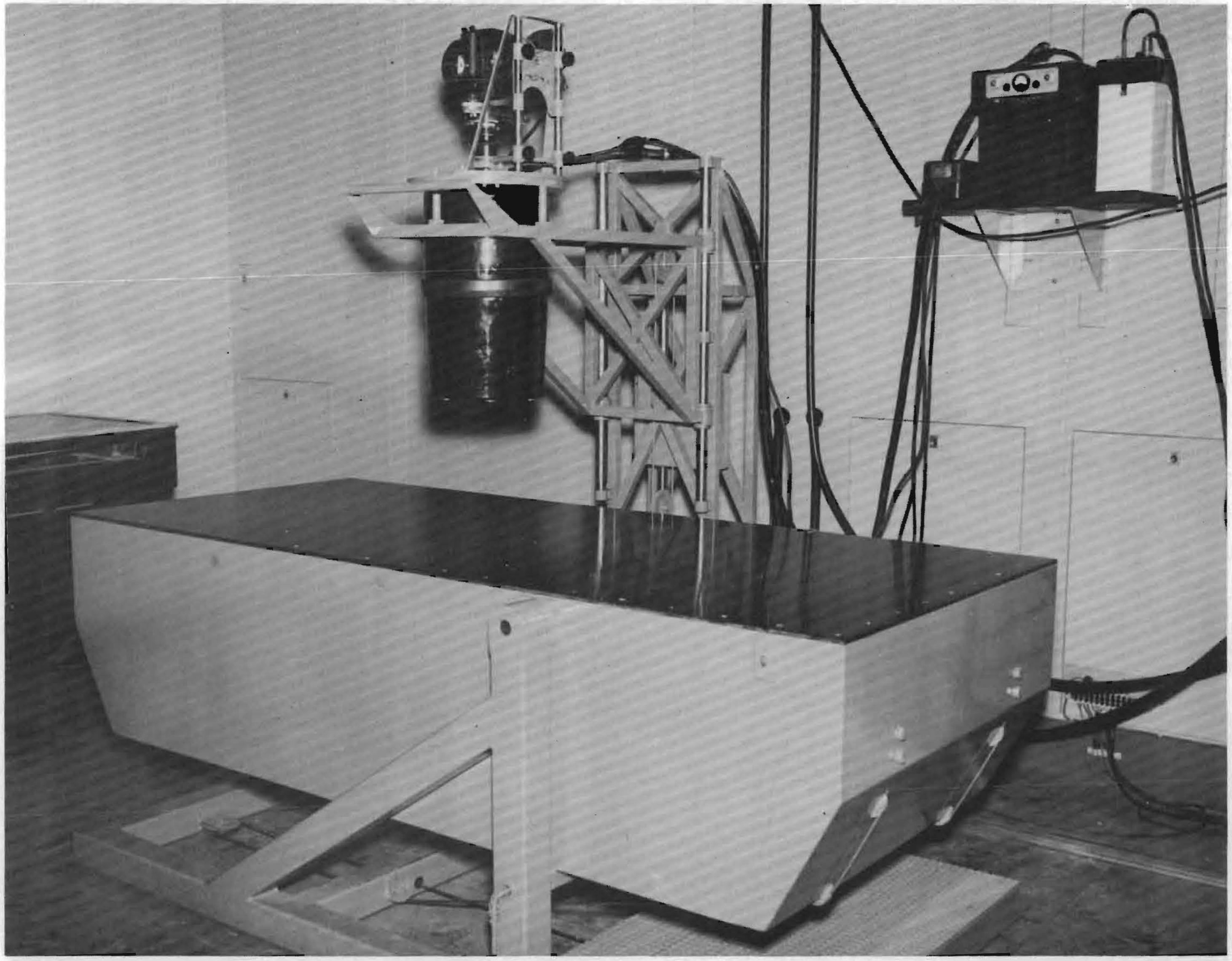


Figure 4. View of the Special X-Ray Table in a Horizontal Position.

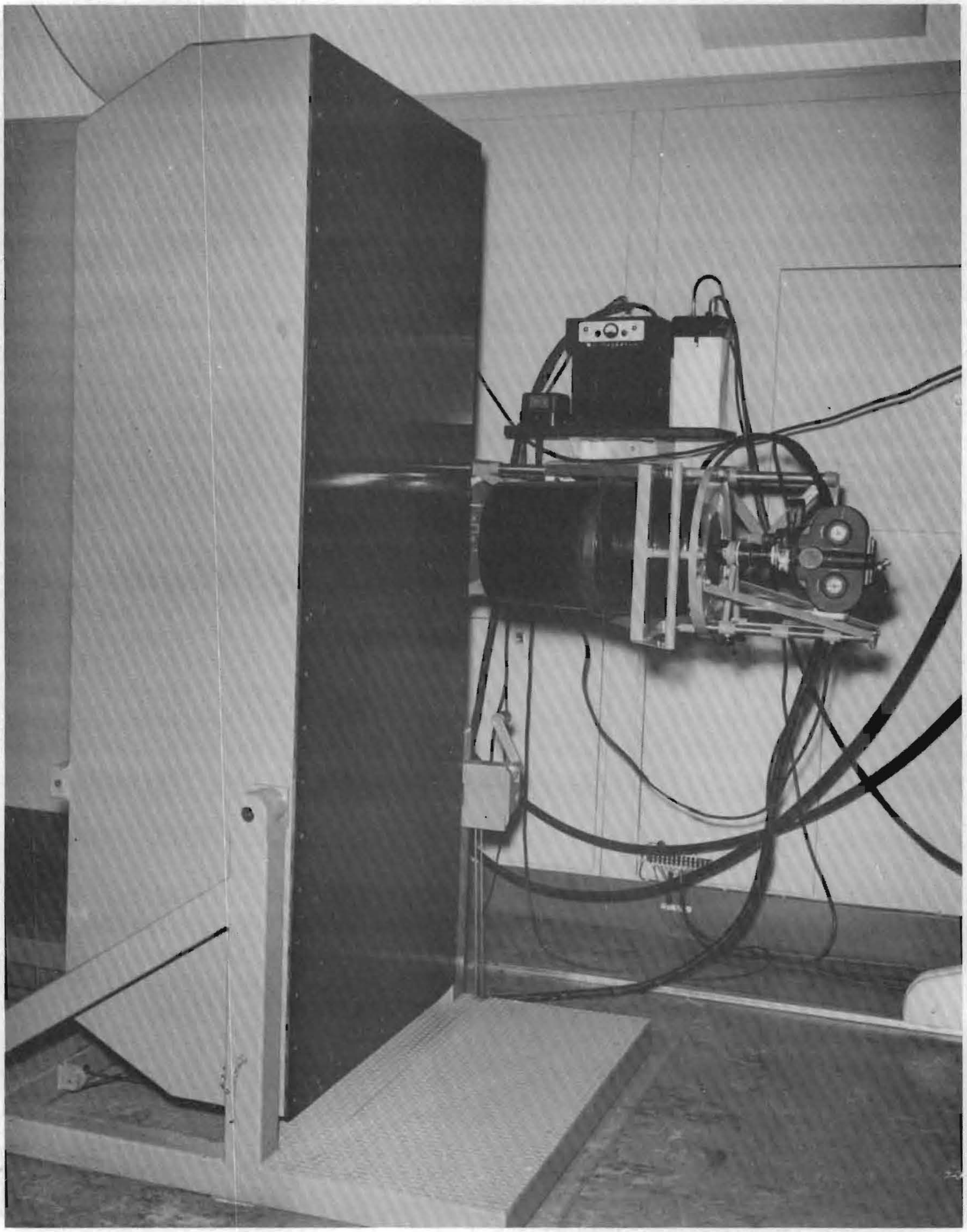


Figure 5. View of the Special X-Ray Table in a Vertical Position.

of this report period. Provisions were made, however, for the fabrication of such a mounting so that this addition can be readily made.

A mount for the Arriflex camera was not constructed because the available lenses were not adaptable to this camera. Suitable lense adaptation will be made so that the Arriflex camera can be used instead of the "Eyemo".

V. CONCLUSIONS

As mentioned in the previous section, it is believed that a better selection of film and film processing may be possible, but for the remainder of this project tests will be conducted using Eastman Special Linagraph Ortho film. As before, this film will be processed by the U. S. Public Health Service.

Upon receipt of the new Philips image-intensifier, a re-evaluation of that tube will be made. The nonuniformity in the output image of the Westinghouse image-intensifier makes its further evaluation questionable.

An amplification factor could be obtained from a comparison of the technique curves for the various systems. However, due to the uncertainties mentioned previously, the present technique curves are not considered accurate enough to warrant their use in the determination of amplification factors. These curves are reported as a matter of record only, with the understanding that re-evaluation of the systems may substantially change the results reported herein.

VI. PROGRAM FOR THE NEXT INTERVAL

After the completion of components necessary to mount the Philips tube on the special X-ray table, an evaluation of the new Philips tube will be made and the Arriflex camera will be mounted and used in conjunction with the image intensifier. The Arriflex is to be preferred because of its built-in monitoring system.

Further clinical studies will be made as subjects become available. Special phantoms[1] will be constructed and will be used to further evaluate the system.

VII. PERSONNEL

The personnel engaged on this project during the period covered by this report were:

Name	Position	Approximate Hours Worked
Brown, J. L.	Assistant Research Physicist	40
Goodman, R. M.	Research Engineer	65
Simpson, W. C.	Research Associate	140
Tolan, J. H.	Project Director	90
Williamson, A. E.	Research Physicist	155
Youmans, H. D.	Research Assistant	205

Respectfully submitted:

J. H. Tolan
Project Director

A. E. Williamson
Research Physicist

Approved:

J. E. Boyd, Chief
Physical Sciences Division

W. C. Simpson
Research Associate

-----

[1] Ove Mattson, "Practical Photographic Problems in Radiography," Acta Radiologica, Supplementum 120, Stockholm, 1955, 206 pp.

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY REPORT NO. 5

PROJECT NO. A-203

RESEARCH ON ELECTRONIC CINÉFLUOROGRAPHY

-o-o-o-o-

CONTRACT NO. DA-36-039-sc-64615
DEPARTMENT OF THE ARMY PROJECT NO. 3-99-04-052
SIGNAL CORPS PROJECT NO. 195B

-o-o-o-o-

JUNE 15, 1956

PLACED BY THE U. S. ARMY
SIGNAL CORPS ENGINEERING LABORATORIES
FORT MONMOUTH, NEW JERSEY

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY REPORT NO. 5

PROJECT NO. A-203

RESEARCH ON ELECTRONIC CINÉFLUOROGRAPHY

by

ARTHUR E. WILLIAMSON

OBJECT: To determine diagnostic suitability of electronic cinéfluorography

PLACED BY THE U. S. ARMY
SIGNAL CORPS ENGINEERING LABORATORIES
FORT MONMOUTH, NEW JERSEY

MARCH 15 to JUNE 15, 1956

TABLE OF CONTENTS

This report contains 21 pages

LIST OF FIGURES

I. PURPOSE

The purpose of this project is to provide information regarding the suitability of electronic image amplification in cinéfluorography. The project consists of an experimental study of commercially available electronic-image-amplifying devices, which will be used in a system incorporating a motion picture camera for recording the image formed on a fluorescent surface by an X-ray beam.

The work is divided into four principal tasks as follows:

(A) the evaluation of nonelectronic cinéfluorography to obtain basic information on contrast, exposure factors, detail and overall system efficiency;

(B) the evaluation of electronic cinéfluorography to determine which diagnostic procedures are possible with image amplification and to correlate information obtained in Task A;

(C) the fabrication of a laboratory model using an image-amplifying tube;

(D) the development of accessory items which would be useful in analyzing film results if time and funds permit.

II. ABSTRACT

As a result of conferences with other persons who have been working in the field of cinéfluorography, it was decided that film processing should be done by the same group who made the exposures and that carefully controlled film processing methods must be employed. Results obtained with the new procedures justify the change. The revised constant density curves for the non-electronic system are almost completed and will be given in the next report. A replacement Philips image-amplifier tube has been received and installed, and the Arriflex camera has been mounted. The Westinghouse Electric Corporation has agreeed to replace the Westinghouse image-amplifier now owned by the project. A review of the basic properties of photographic emulsions is attached as an appendix.

III. CONFERENCES

During the week of May 7 to May 11 Mr. A. E. Williamson visited the Friez Instruments Division of the Bendix Aviation Corporation in Baltimore, Maryland; the Department of Radiology at Johns Hopkins University in Baltimore, Maryland; the Department of Radiology at the University of Rochester Medical School in Rochester, New York; the Eastman Kodak Research Laboratory in Rochester, New York; and the Westinghouse Research Laboratory in East Pittsburgh, Pennsylvania. Mr. Williamson was joined by Dr. W. C. Simpson for conferences at the Eastman Kodak Research Laboratory and at the Westinghouse Research Laboratory.

Characteristics of the Lumicon, a closed circuit television system manufactured by Friez Instruments Division, were discussed with Mr. J. H. Waite, Mr. R. B. Stevenson, Mr. Robert Lee and Dr. Ralph Sturm at Friez Instruments and with Dr. Russell Morgan at Johns Hopkins University. Dr. Morgan is using the Lumicon for both X-ray diagnosis and X-ray therapy monitoring. Other applications of the Lumicon have been made to the monitoring of high energy therapy units such as the two Mev Van der Graaff machine at the Public Health Services Hospital at Bethesda, Maryland.

Some data on the characteristics of the Lumicon were obtained. According to Dr. Morgan, for a radiation intensity of 100 milliroentgens per second at the screen and with no absorber, the Lumicon will 'resolve' a steel wire of 0.25-mm diameter; with a 10-cm masonite absorber (simulating a chest) and a radiation intensity of 10 milliroentgens per second at the screen, the system will 'resolve' a 0.4-mm wire; for an absorber simulating the lower abdomen, an intensity of 1 milliroentgen per second at the screen, the system will 'resolve' a 0.6-mm wire. The use of the word 'resolve' here is in the sense of the ability to discern the given object from the background. Dr. Morgan did not say but it is assumed that the wires used as test objects were located close to the fluorescent screen.

Using a Lumicon with an f/1.5 lens,* Mr. Williamson and Mr. Stevenson obtained the following data during the visit. The test setup consisted of a portable Keleket X-ray unit, a Lumicon system, and an 8.5-cm Masonite absorber. With a target-to-screen distance of 30 in., the absorber was located approximately midway between the X-ray tube and the Lumicon screen. Using an opaque (barium-filled) catheter, approximately 1 mm in diameter, with the catheter on the tube-side of the absorber, the catheter could be 'resolved' at a minimum 'technique' of 45 KVP and 1 MA; for the catheter on the screen-side of the absorber, the minimum 'technique' for which the catheter could be 'resolved' was 62 KVP and 1 MA. Then a wire screen with 20 wires per inch, each wire having a diameter of 0.41 mm, was used as a test object. No additional absorber was used. With the wire screen located 15 cm from the fluorescent screen, the wires of the screen could be 'resolved' for a minimum 'technique' of 62 KVP and 3 MA. With the wire screen adjacent to the fluorescent screen, 'resolution' could not be achieved. The word 'technique' is used by the medical profession to denote a set of radiographic conditions for which an acceptable radiograph is obtained. For example, if it is desired to X-ray an object of a given thickness and density and to obtain a radiograph on a given type of film, then the 'technique' to obtain

- - - - -

* Unfortunately a light tunnel for the f/0.75 Fluoro Ektar lens was not available so no tests could be made with that lens.

the radiograph would be ( ) KVP, ( ) MA and ( ) S. These factors are discussed later. In ciné operations, the exposure S is set by the framing speed of the camera or by the duration of a pulse of X-radiation.

The Lumicon is very impressive as a light amplifier; a legible video picture was obtained when, with some dark adaptation, the outline of the object could just barely be discerned directly.

At the X-ray Plant of the Westinghouse Electric Corporation in Baltimore, Mr. D. H. Steinweg discussed the new standards for the production of Westinghouse image-amplifier tubes. These new requirements are much more rigid than the old requirements, but the possibility of obtaining a tube which would not be ideally suited for cinéfluorography still exists. Westinghouse has agreed to replace the image-amplifier tube that the project now owns and which has been found to be unsatisfactory for an evaluation study.

Mr. Sydney Weinberg and Dr. J. S. Watson of the Department of Radiology, University of Rochester Medical School, reviewed some 16-mm film of tests* made at Emory University under this project with the conventional (non-electronic) system and with both of the image-amplifier tubes. Several comments were made on the quality of the film. First, better results would probably be obtained by developing the negatives for 5 or 6 minutes in Kodak Liquid X-ray Developer to a gamma of two (just short of fogging the film). It is also imperative that developing facilities be available at the location of the tests so that results of a given study can be readily available and so that development can be adequately controlled. Second, without a shutter, the conventional system cannot be expected to give sharp pictures.

- - - - -

* The tests were made on 35-mm film and "printed-down" to 16 mm.

Even though the X-ray beam is off, the screen persistence is such that a smearing of the picture will occur during the film-transport time.

Construction of special X-ray phantoms and properties of special high-contrast X-ray films were discussed with Dr. Herman Seemann at the Eastman Kodak Research Laboratory. These special phantoms are constructed of bone, glue-impregnated sponge, wax, etc., to simulate the human anatomy.* A phantom which would be more easily constructed and which would probably be satisfactory for this work was constructed as follows: a 10-cm Lucite water tank had suspended in it pieces of bone, alphabet soup, nylon tubing, glue-impregnated sponge, etc., all suitably waterproofed by enclosure in plastic bags. This type of phantom can be quickly (and cheaply) obtained and satisfactorily simulates the varying densities in the human body. Dr. Seemann's group has a pair of matched projectors which project the images from two different films side-by-side on a screen. These projectors can be used to compare radiographs of the same object which differ in some respect.

In discussions with Dr. Fitzhugh Marshall at the Westinghouse Research Laboratory, it was revealed that the Farrand Optical Company has developed a closed-circuit television system which is approximately 10 times more sensitive than the Lumicon and that Westinghouse has a system 100 times more sensitive than the Lumicon. Dr. Marshall also pointed out that Westinghouse's Fluorex image-amplifier system could be much improved by utilizing developments of the past few years, but that the cost-per-unit would approach twenty thousand dollars. Concerning the Philips image-amplifier tube, Dr. Marshall believes the "gas spot" in the tube is due to the liberation of gas molecules

- - - - -

* A brief report on the construction of these phantoms is given in Radiology, Vol. 64, No. 1, p. 114, January 1955.

from the organic coating on the X-ray phosphor, and that this fault is inherent in the Philips tube because an organic, rather than inorganic coating is used.

Dr. John Coltman of the Westinghouse Research Laboratory discussed methods of determining the resolution of image-amplifier systems. The most important conclusion that he has reached is that resolution cannot be stated as one number. Dr. Coltman has studied a method of specifying the imaging properties of a system by the response of the system to an input that is sinusoidal in space.*

- - - - -

* This method is discussed in The Journal of the Optical Society of America, Vol. 44, No. 6, pp. 468-471, June 1954.

IV. FACTUAL DATA

A. Task A. Evaluation of Nonelectronic Cinefluorography

In the operation of any X-ray device where permanent records are desired the end product is the radiograph, or photographic negative. This negative can be produced in several ways. One method is to let the X-ray impinge directly on the negative, that is, the X-rays activate the film emulsion directly. Usually a double-coated film is used in this method. An alternative to this direct method utilizes a pair of intensifying fluorescent screens, one on each side of the negative, to intensify the picture by the light from the screens. A third method of obtaining a radiograph uses an intermediate step where the X-rays are converted to visible light by a fluorescent screen. The output of this fluorescent screen is photographed. The latter method is employed in all three systems in this evaluation, except for the image-amplifier tubes where there is an additional stage. This additional stage is the conversion of the light coming from the X-ray-energized fluorescent screen to electrical energy which is focussed and amplified before it reaches another fluorescent screen. This second fluorescent screen is the one which is photographed.

The darkening of the film by X-rays, whether direct or with a screen, is called the radiographic effect. Several empirical relationships have been written for the radiographic effect.* The most commonly used relationship is

$$\text{Radiographic effect} = \frac{C\ (MA)(S)(KVP)^n}{d^2}$$

- - - - -

* See, for example, Physical Foundations of Radiology by Glasser, Quimby, Taylor and Weatherwas. Published by Hoeber. Or Acta Radiologica, Vol. 36-4, pp. 311-323, 1951.

where

C = a constant characteristic of the complete X-ray-to-film processing system

MA = the X-ray tube current in milliamperes

KVP = the peak X-ray voltage in kilovolts

n = a number (approximately 5) for conventional radiography

S = the X-ray exposure time in seconds

d = the distance from the X-ray source to the fluorescent screen or film

The value of n for electronic image amplification systems has not been established. Preliminary work here has indicated a value between three and four for the Philips image-amplifier tube.

For a given system, if the radiographic effect which causes a film density D_1 is R_1, then if the parameters MA, S, KVP, or d are varied in such a manner that the radiographic effect remains R_1, the density should remain D_1. In general then, if, in addition to the above constants, the properties of the test object, such as thickness and X-ray absorption, are known it is possible to calculate the correct values of KV and MA to give a radiograph of the desired density.

Without calculating the values of these constants, the same information can be obtained from a set of experimentally-determined curves, commonly called constant-density or 'technique' cruves. On these curves, values of MAS, that is, tube current in milliamperes multiplied by X-ray exposure time in seconds, are plotted versus test object thickness with KVP as a parameter giving a family of curves for KVP = a constant, all curves being determined for a given film density and a given X-ray-tube-target-to-fluorescent-screen distance.

In Quarterly Progress Report No. 2, such curves were reported for the conventional or nonelectronic system. In attempting to use these curves to determine the proper 'techniques' for animal studies, certain discrepancies were noted. Investigation disclosed that points on these curves had been obtained by exposing the fluorescent screen to X-rays with specified X-ray tube current (MA) and X-ray exposure time (S) with the film in place and with no camera shutter. This meant that the film was exposed to the output of the screen both during the X-ray exposure and during the screen afterglow. The afterglow is a function of both the X-ray energy (KV) and the X-ray exposure time. During normal (ciné) operation, the X-ray exposure time is set at 1/60 sec. At this exposure, the afterglow is negligible. However, at some of the higher MAS values on the technique curves, the longer exposure times which were used in obtaining the data made the exposure of the film quite different from that which would have been obtained in 1/60 sec where the screen afterglow is small and negligible. For this reason the curves are not considered reliable. They will be redetermined by operating the system as it is operated in actual use. This procedure will consume more film than the previous one because approximately 40 in. of film are used on each test during acceleration and deceleration of the film.

Another factor which influences the technique curves is the processing of the film. As already pointed out, several people have questioned the film processing procedure previously used.

For these reasons the constant-density or 'technique' curves are being redetermined for the nonelectronic system. This work has progressed and is near completion. It should be noted at this point that a technique curve applies only to a particular set of carefully-controlled conditions. The conditions under which these curves were obtained will be presented, along with the curves, in the next report.

B. Task B. Evaluation of Electronic Cinefluorography

The replacement Philips image-amplifier tube has been received and mounted on the special X-ray table. A mount for the Arriflex camera which can be used interchangeably on either of the image-amplifier tubes has been designed and constructed. A DC power supply to operate the Arriflex camera has been ordered and received. An attempt to obtain from commercial sources the lenses which are necessary for an optimum (f/1.5) optical system proved fruitless. However, the Signal Corps possesses the required lenses and arrangements have been made to obtain these lenses on loan. Preparations here are complete, and when these lenses are received the evaluation of the new Philips image-amplifier tube can proceed.

The Westinghouse Electric Corporation has agreed to replace the image-amplifier tube which the project now owns. No definite date has been set for the exchange, but assurance was given that it would be at the earliest possible time.

As stated in the last report, the Eastman Kodak Special Linagraph Ortho film will be used for comparing the three systems. This choice was made because this film seems best for the nonelectronic system, where the maximum sensitivity in film is desirable. However, this film has an appreciable inherent background. Efforts of the manufacturer have not succeeded in clearing it up. At a gamma of 1.84, this background is recorded as a density of about 0.3. This is appreciable when one realizes that a density of about 1.0 is preferred by most radiologists for diagmostic films. For this reason, and also because this film has a rather large grain size, it has been suggested that better pictures may be obtained with the electronic systems using a slower film, such as Tri-X or Plus-X. For purposes of comparing the systems, the Eastman Kodak Special Linagraph Ortho film will still be used, but some of these other films will be investigated further for use with the electronic systems.

V. CONCLUSIONS

As a result of information obtained during the technical conferences discussed under Section III and from subsequent experimental studies, some changes have been made in the approach to the problem. First, and probably most important, film processing will be done in a room adjacent to the X-ray laboratory at Emory University. Kodak Liquid X-ray Developer will be used and the gamma to which the film is developed will be controlled. Two modified 14-in. by 17-in. X-ray plate holders have been obtained. Each of these holders has a capacity of about 22 ft. of 35-mm film. A standard refrigerated plate-film tank is available for film processing. The problem of exact duplication of film processing procedures has been overcome by exposing a section of each film strip, which is to be developed separately, with an aluminum stepwedge at a set technique. In addition, the time of processing and the strengths of the solutions are carefully controlled. As a result, errors of large magnitude are not encountered and by plotting the stepwedge calibration on each strip against a standard obtained by averaging many such determinations, small errors may be corrected. Results obtained using this procedure have been very encouraging.

The amplification factor of an image amplifier is defined as the ratio of the radiographic effect for the nonelectronic or conventional system to the radiographic effect for the image amplifier which produce the same density negative for the same test object and X-ray-tube-target-to-fluorescent-screen distance. As soon as a series of technique curves for each system has been obtained, it will be possible to determine the amplification factors of the electronic systems for the conditions under which the technique curves were obtained. Further investigation is required to determine how general such an amplification factor will be. A true amplification factor would seem to be the ratio of radiographic effects which was obtained for the optimum operating conditions of each system that would produce the same density radiograph for the same test object, regardless of the type of photographic film or processing used. Determining this type of amplification factor would be an endless task. For the purpose of comparing the systems, amplification factors will be obtained from the technique curves which are being determined using the Eastman Kodak Special Linagraph Ortho film and the Kodak Liquid X-ray developer.

Further studies of the system efficiencies for other films will be made as time permits. In the meantime, a review of the basic properties of film emulsions is included as an appendix to this report.

VI. PROGRAM FOR THE NEXT INTERVAL

The determination of the technique curves for the nonelectronic system will be continued. As soon as the lenses for the Arriflex camera are received, technique curves for the Philips image-amplifier tube will be determined. Similarly, curves for the Westinghouse image-amplifier tube will be obtained as soon as a replacement tube is supplied.

A special phantom which can be used to determine the minimum size of a blood vessel containing contrast media which can be resolved has been constructed. The minimum resolvable vessel size for each system will be determined as soon as the technique curves for the three systems are available.

VII. PERSONNEL

The personnel engaged on this project during the period covered by this report were:

Name	Position	Approximate Hours Worked
Brown, J. L.	Assistant Research Physicist	50
Cerney, J. C.	Assistant Research Engineer	70
Goodman, R. M.	Research Engineer	45
Simpson, W. C.	Research Associate	130
Tolan, J. H.	Project Director*	110
Williamson, A. E.	Project Director**	210
Youmans, H. D.	Technical Assistant	390

Respectfully submitted,

Arthur E. Williamson
Project Director

Approved:

J. E. Boyd
J. E. Boyd, Chief
Physical Sciences Division

-----

* Terminated June 1, 1956

** Effective June 1, 1956

VIII. APPENDIX

Properties of Photographic Emulsions

By W. C. Simpson

Thus far in this work, several different types of photographic emulsions have been used and some preliminary comparisons of these materials have been made. However, it would be desirable in order to determine the optimum film for each system to undertake a more thorough study of photographic emulsion characteristics. Consequently the following review of the basic properties of film emulsions has been included in this report.

The first three of the major properties of an emulsion may be determined from the characteristic curve of the emulsion (Figure 1) which shows the relationship between exposure received by the emulsion and the resulting density of the developed image. The 'exposure' is the total amount of electromagnetic radiation, whether light, X-radiation, etc. X-ray exposure is measured in milliampere-seconds (MAS), that is, X-ray tube current in milliamperes times time in seconds, for different values of X-ray tube voltage in kilovolts (KVP), and density is defined as $\log_{10} I_o/I$, where I_o is the intensity of a photometering beam and I is the intensity of that beam transmitted by the plate; for complete transmission ($I_o = I$), $\log I_o/I = 0$.

The characteristic curve (Figure 1) begins at a point A ("threshold exposure" at which blackening of the film first becomes perceptible). After a curved "toe" AB, the curve becomes very nearly straight in the region BC, density being directly proportional to the log of the exposure received by the film.

The portion of the curve beyond point C is of no interest here, but indicates a reversal of density with prolonged exposure. The point of

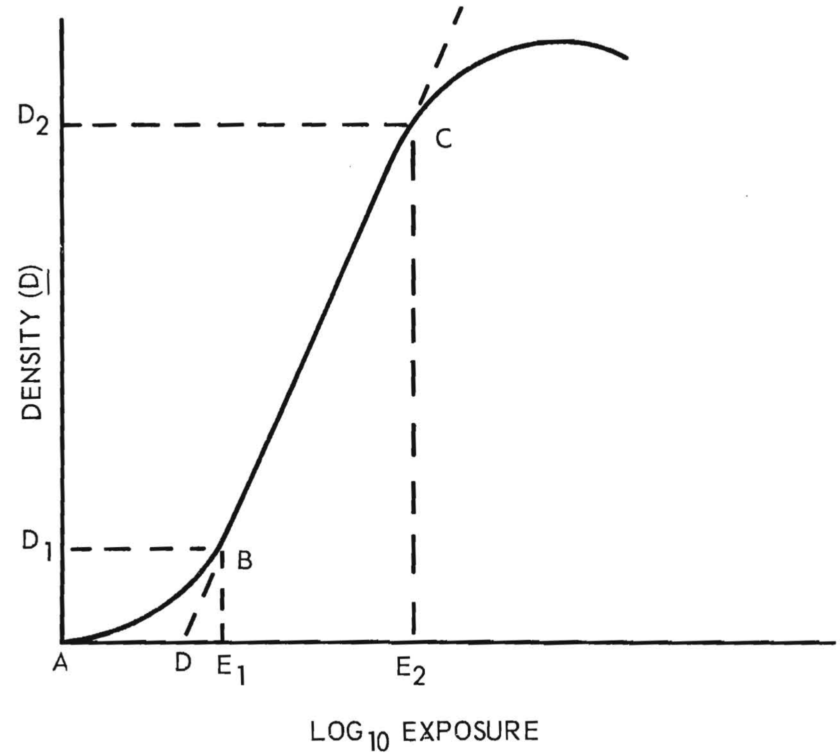


Figure 1. Characteristic Curve of a Photographic Emulsion.

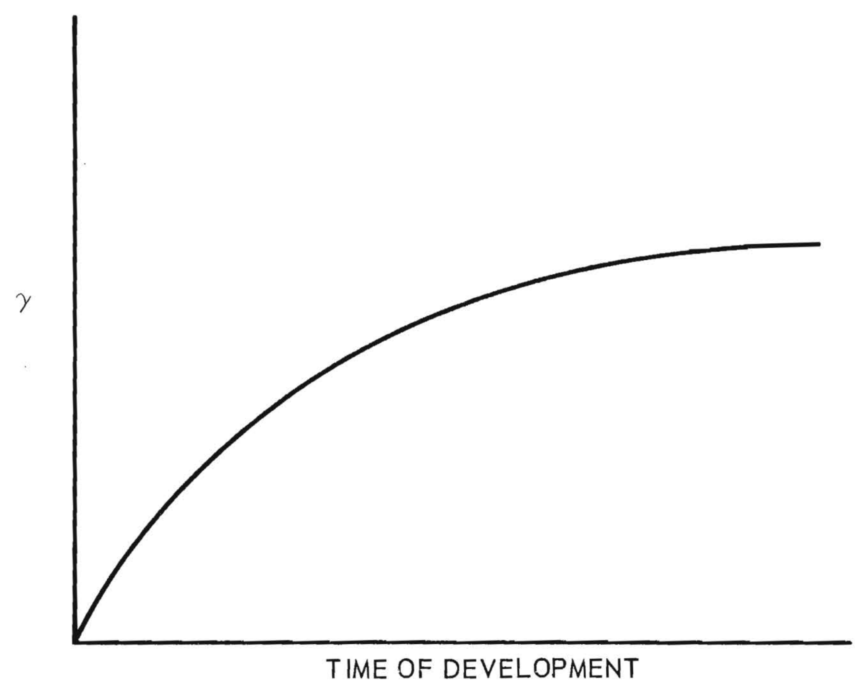


Figure 2. Dependance of γ upon Development Time.

intersection D of the straight line portion BC of the curve with the exposure axis determines the exposure AD known as the "inertia" of the emulsion. The inertia of the film is regarded as an indication of film speed, films having small inertia being designated "fast" and those having comparatively large inertia being designated "slow" films. The slope of the straight line portion of the curve is the development factor, or "gamma" (γ) of the emulsion,

$$\gamma = \tan \theta = \frac{D_2 - D_1}{\log_{10} E_2 - \log_{10} E_1} .$$

If $\gamma = 1$, density increases in direct proportion to the log of exposure, a condition which is usually desired in most pictorial photographic work for proper reproduction of different intensities in different regions of a picture. If a film has high gamma, $\gamma > 1$, it is said to be of high contrast or "hard". If $\gamma < 1$, the film is low contrast or "soft". According to Weinberg and others in the field of Radiology, a higher contrast is desirable, ($\gamma \rightarrow 2$ being suggested). The gamma of a given emulsion changes with the degree of development, as shown in Figure 2, increasing rapidly at the first of the development and then less rapidly as development continues.

For photometric purposes, it will be most desirable to use a development routine which will produce nearly the same gamma on each film strip.

The "latitude" of the emulsion is defined as the ratio of the maximum exposure to the minimum exposure resulting in satisfactory reproduction of the image. This range is essentially limited by the length of the straight segment BC of the characteristic curve. For best discrimination between small intensity differences, and therefore, for best accuracy in photometeric studies, it is desirable to operate within the linear portion of the curve, using a film with as high gamma as will give the required latitude.

Close examination of any photographic emulsion will reveal a granular structure or "graininess" of the film. This grain depends partly on the physical size of the silver halide particles in the emulsion, but to a greater extent on the grouping of grains which results from development of the film. This grouping, in turn, depends somewhat on the developer employed. Fine-grain developers can reduce the graininess by a factor of approximately two over general purpose developers. A small grain size is especially desirable for strips which are to be projected and enlarged several times. Grain size is also a factor which greatly influences resolution, the resolution increasing as grain size decreases.

In the field of optics and photography, the word 'resolution' has a strict definition; it is the number of uniform lines or obstructions per unit distance which can just be distinguished as separate lines. These lines are uniformly spaced with the width of the spaces equal that of the obstructions. In the X-ray field 'resolution' is used rather loosely to mean either the number of evenly spaced lines per unit distance which can just be distinguished or to mean the smallest object which can be discerned against a given background. As mentioned above, graininess has a great influence on resolution, in particular on optical resolution; however, the effects of turbidity and contrast cannot be overlooked.

Turbidity is defined as the spreading of image size with increasing exposure. This spreading is largely due to internal reflections of light by the silver grains in relatively coarse-grained films and is thus independent of wavelength. On the other hand, diffraction scattering appears in fine-grain films and decreases with increasing wavelength.

Resolution is also dependent on contrast since high contrast aids in differentiating between closely spaced lines. Fine-grained films usually have high contrast and low turbidity, thus resulting in better resolution. Grain and contrast are influenced by development procedure and type of developer used, and therefore resolution is, in turn, determined partly by development.

The properties mentioned here for all photographic emulsions show some dependence on wavelength of the exposing radiation. If spectral-response studies are made for the fluorescent screens being used in the course of this project and reveal greatly different predominant wavelengths of the emitted light, some further investigation of this phase will be necessary.

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY REPORT NO. 6

PROJECT NO. A-203

RESEARCH ON ELECTRONIC CINÉFLUOROGRAPHY

- o - o - o -

CONTRACT NO. DA-36-039-sc-64615
DEPARTMENT OF THE ARMY PROJECT NO. 3-99-04-052
SIGNAL CORPS PROJECT NO. 195B

- o - o - o -

SEPTEMBER 15, 1956

PLACED BY THE U. S. ARMY
SIGNAL CORPS ENGINEERING LABORATORIES
FORT MONMOUTH, NEW JERSEY

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY REPORT NO. 6

PROJECT NO. A-203

RESEARCH ON ELECTRONIC CINÉFLUOROGRAPHY

by

ARTHUR E. WILLIAMSON

OBJECT: To determine diagnostic suitability of electronic cinéfluorography

PLACED BY THE U. S. ARMY
SIGNAL CORPS ENGINEERING LABORATORIES
FORT MONMOUTH, NEW JERSEY

JUNE 15 to SEPTEMBER 15, 1956

TABLE OF CONTENTS

This report contains 16 pages

LIST OF FIGURES

I. PURPOSE

The purpose of this project is to provide information regarding the suitability of electronic image amplification in cinéfluorography. The project consists of an experiment study of commercially available electronic-image-amplifying devices, which will be used in a system incorporating a motion picture camera for recording the image formed on a fluorescent surface by an X-ray beam.

The work is divided into four principal tasks as follows:

(A) the evaluation of nonelectronic cinéfluorography to obtain basic information on contrast, exposure factors, detail and overall system efficiency;

(B) the evaluation of electronic cinefluorography to determine which diagnostic procedures are possible with image amplification and to correlate this information with information obtained in Task A;

(C) the fabrication of a laboratory model for cinéfluorography using an image-amplifying tube;

(D) the development of accessory items which would be useful in analyzing film results if time and funds permit.

II. ABSTRACT

Constant-density curves for the nonelectronic system and for the Philips image-intensifier-tube system are reported. Resolution studies have been made with both systems of a test object which consisted of a Plexiglass tank filled with water in which a number of plastic tubes filled with Diodrast were suspended.

Detailed comparisons of the characteristics of the systems are being delayed until a new Westinghouse image-intensifier tube has been received and its characteristics determined.

III. CONFERENCES

On August 3 Mr. Williamson visited the Signal Corps Engineering Laboratories at Fort Monmouth, New Jersey. The status of work on the project was discussed with Mr. Edward P. Kennedy and Mr. Joseph DeClerk. The special lenses for use with the Arriflex camera were obtained during this visit.

IV. FACTUAL DATA

A. Task A. Evaluation of Nonelectronic Cinéfluorography

Constant-density or technique curves for the nonelectronic system have been determined. These curves are given in Figure 1. As emphasized in Progress Report No. 5, these data are for a given system, from X-ray source to photographic film. This system is typical of the cinéfluorographic systems used in clinical practice. In the following paragraphs the system and the experimental procedure used in obtaining these data will be discussed in some detail.

The functional system is shown diagramatically in Figure 2. A photograph of this system was presented as Figure 1 in Progress Report No. 1. The X-ray tube used was a Machlett Super Dynamax. A distance of 30 inches from the X-ray-tube target to fluorescent screen was used, with the Masonite-Prestwood test object placed on the table at a distance of three-fourths inch from the screen. The fluorescent screen is a Patterson E-2 screen--the type commonly used in fluoroscopy. The light from the screen is directed to the Wray f/0.71 lens by a front-surface mirror. The Wray lens is used with a modified Cunningham 35mm camera. The camera is driven synchronously at 15 frames per second and the X-ray tube is pulsed on for one-sixtieth of a second by the same synchronizing mechanism that drives the camera. No shutter is used with the system.

The photographic film used was Kodak Special Linagraph Ortho, emulsion No. S. O. 1130. Film processing was in Kodak Liquid X-ray Developer at 68 degrees F. for six minutes. A calibrated stepwedge was exposed on each strip to be developed and was used to correct for minor variations in development.

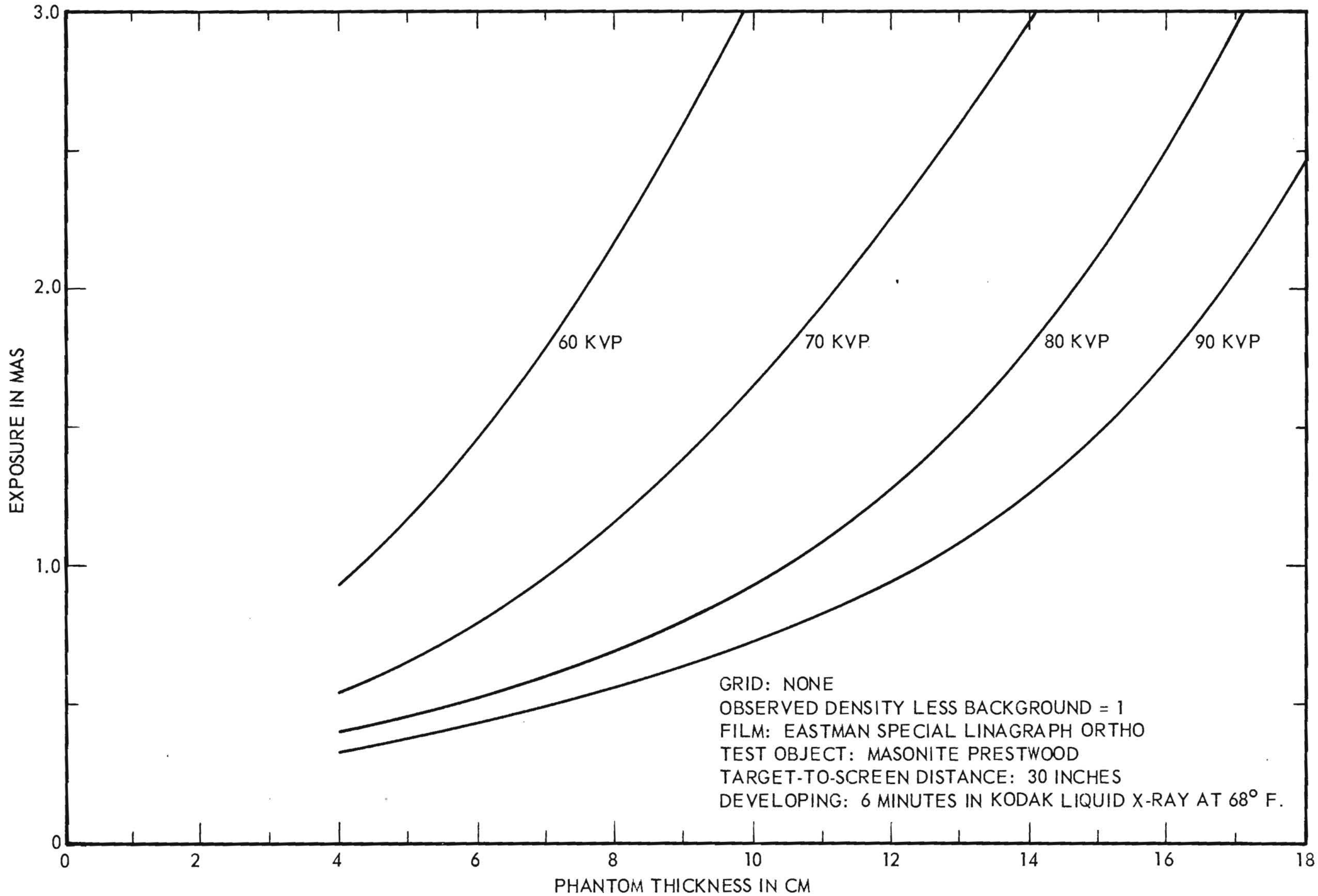


Figure 1. Constant-Density Curves for the Nonelectronic System

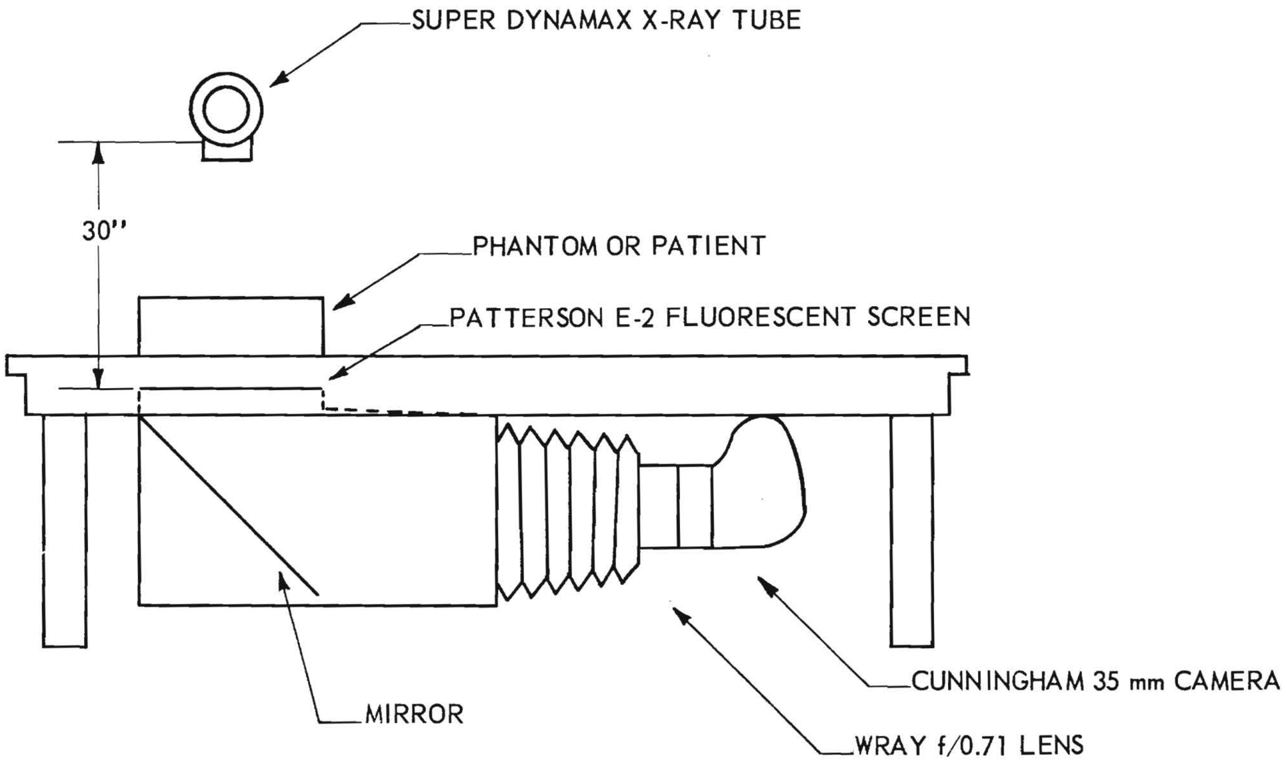


Figure 2. Functional Diagram of the Nonelectronic System

The procedure used for determining a point on one of the curves was the following: an estimate was made as to the MAS and KV values necessary to obtain a density of one* for the given test-object thickness, then three exposures were made, all having the same KV, but with variations in MA so that the MAS values enclosed the estimated point, that is, one point was high, one was low, and one was at the estimated value. The optical density of the film for each exposure was determined for at least five frames, then these values were averaged and the inherent background of the film subtracted. This gave a set of three points showing the relationship between MAS and density, D, for constant KV and test object thickness, t. In order to smooth out small variations due to developing procedures, an aluminum penetrameter with 6 steps of $\frac{3}{16}$", $\frac{3}{8}$", ...to $1\frac{1}{8}$" was used as a standard to determine a corrected density, D_c. This was done as follows: the penetrameter was photographed with each test. At the end of the series of tests, an average of each step was made for five frames on each test, then an average value for each step was found for all the tests. By plotting the density values for each step of a test versus this average for all tests in the series, a curve was obtained which related the density for any one test to a corrected density. In further calculations, the corrected density, D_c, was used. This process was repeated for each test. Then the primary data points were plotted on an intermediate curve of MAS versus D_c, for constant KV and t. A smooth curve connecting these points should cross the line $D_c = 1.00$.** The value of MAS which would expose the

- - - - -

* Density as used herein, means the observed density less the "inherent background" of the film. This is the density which is proportional to the radiographic exposure.

**If the curve does not intersect the $D_c = 1.00$ line, the curve may be extrapolated to this line and a more accurate estimate of the MAS for a density of 1.00 can be made and another set of three points obtained.

film to a density of 1.00 is the intersection of this curve and the line D_c = 1.00.

The next and final step was to plot the MAS for a density of 1.00 versus the test object thickness, a curve being obtained for each value of KV. These are the technique curves given in Figure 1. A preliminary study of data taken from day to day indicates that the density actually observed for a particular set of conditions (KVP, MA, t) will be bracketed by limits ten percent each side of a density of one, the density for which these curves were constructed. However, an eye has difficulty differentiating between a density of 0.90 and 1.10, unless the films are side by side, so for clinical studies, these errors are insignificant.

As previously mentioned, the problem of determining the resolution of a system such as this is largely a matter of definition. In medical work, the resolvability of a given size of wire mesh has little meaning, while the ability to resolve the organs of the body (i.e. see their shadows in contrast to the background exposure) is important. In order to determine a meaningful measure of resolvability for this work, a Plexiglass box, approximately 40 x 40 x 25 cm has been constructed. When filled to various depths with water, this box simulates the absorption and scattering within the different parts of the human anatomy. A Plexiglass plate which can be suspended at various depths in this phantom is used to support ten polyethylene tubes of diameters (inside) varying from 0.011" to 0.070". These tubes can be filled with contrast media and the diameter of the minimum resolvable tube determined. This test object gives a measure of the minimum resolvable blood vessel with contrast media at various locations in the body. In this type of work, the contrast-media,

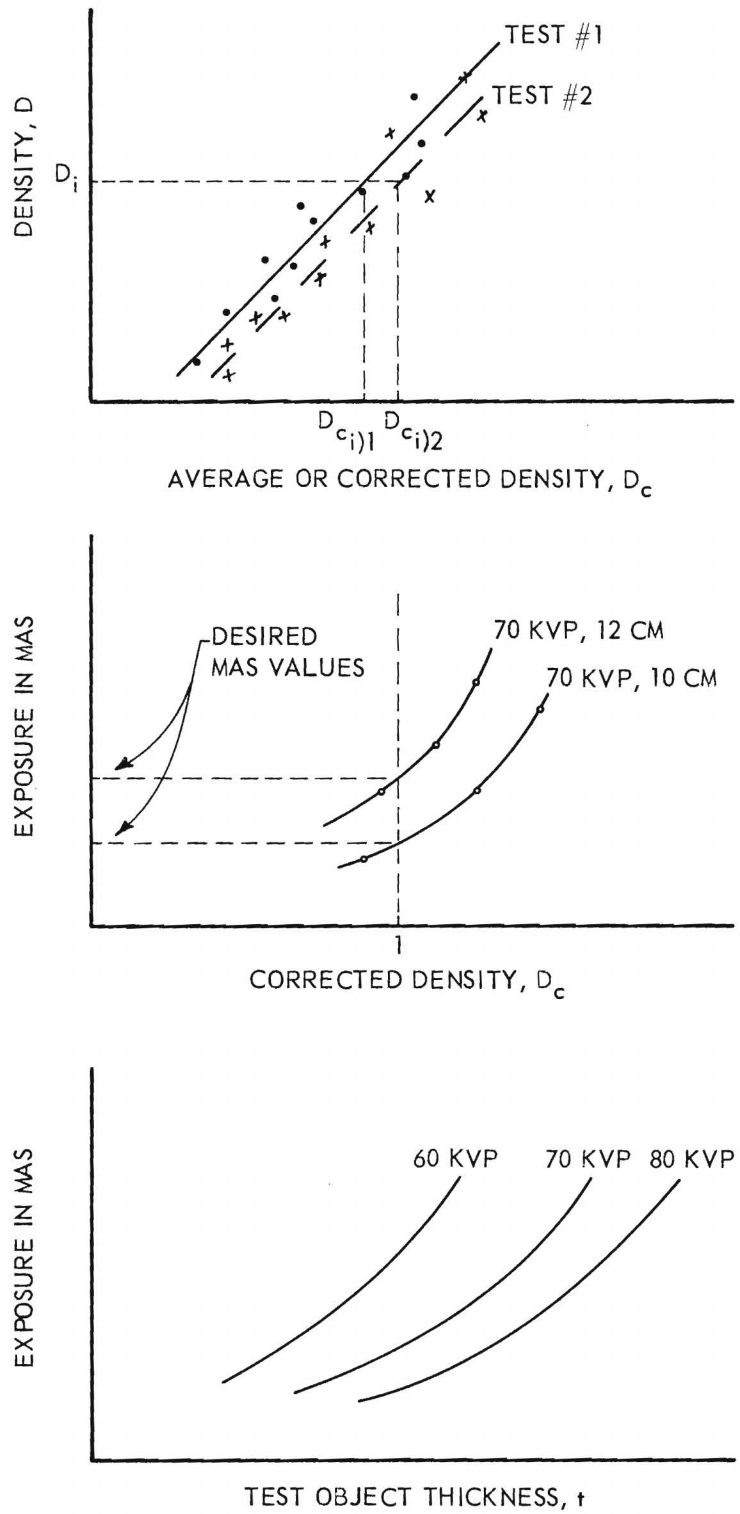


Figure 3. Illustration of Graphical Procedure Used in Obtaining Constant-Density Diagrams

Diodrast, has been most frequently used, and this media was selected for the resolution tests. In preliminary tests using 35 percent Diodrast and 20 cm thickness of water with the tubes at 10 cm, the minimum resolvable diameter was 0.066 inch. A Diodrast concentration of 17.5 percent was also used but failed to give sufficient contrast for resolution.

B. Task B. Evaluation of Electronic Cinéfluorography

The constant-density curves for the Philips image-intensifier tube and its associated optical-and-photographic system are given in Figure 4. The complete system is shown diagrammatically in Figure 5. The intensifier tube is mounted over the special table, while the X-ray tube, a Dynamax 46 Fractional-Focus tube is mounted under the table, 18 inches from the upper surface of the five-sixteenths inch Micarta table top. An X-ray-target-to-fluorescent-screen distance of 30 inches was used, with the test object resting on the table top. A special testplate with nine one-inch diameter holes, varying in depth from 0.1 inch to 0.9 inch in steps of 0.1 inch, was made from a piece of one-inch thick aluminum. A picture of this test plate was made at a fixed KV and MAS on each film strip and these data were used to obtain corrected density values in a manner similar to the use of the stepwedge with the nonelectronic system.

The lens which is furnished with the Philips tube, a 55 mm, f/1.5 Schneider-Kreuznach was used as a coupling lens. An Astro-Gesellschaft 75 mm f/1.8 lens, furnished by the Signal Corps was used as a taking lens on the Arriflex camera. The camera was operated at approximately 16 frames per second. The film used was the Eastman Special Linagraph Ortho which was also used with the nonelectronic system. Film processing was the same as for the nonelectronic system.

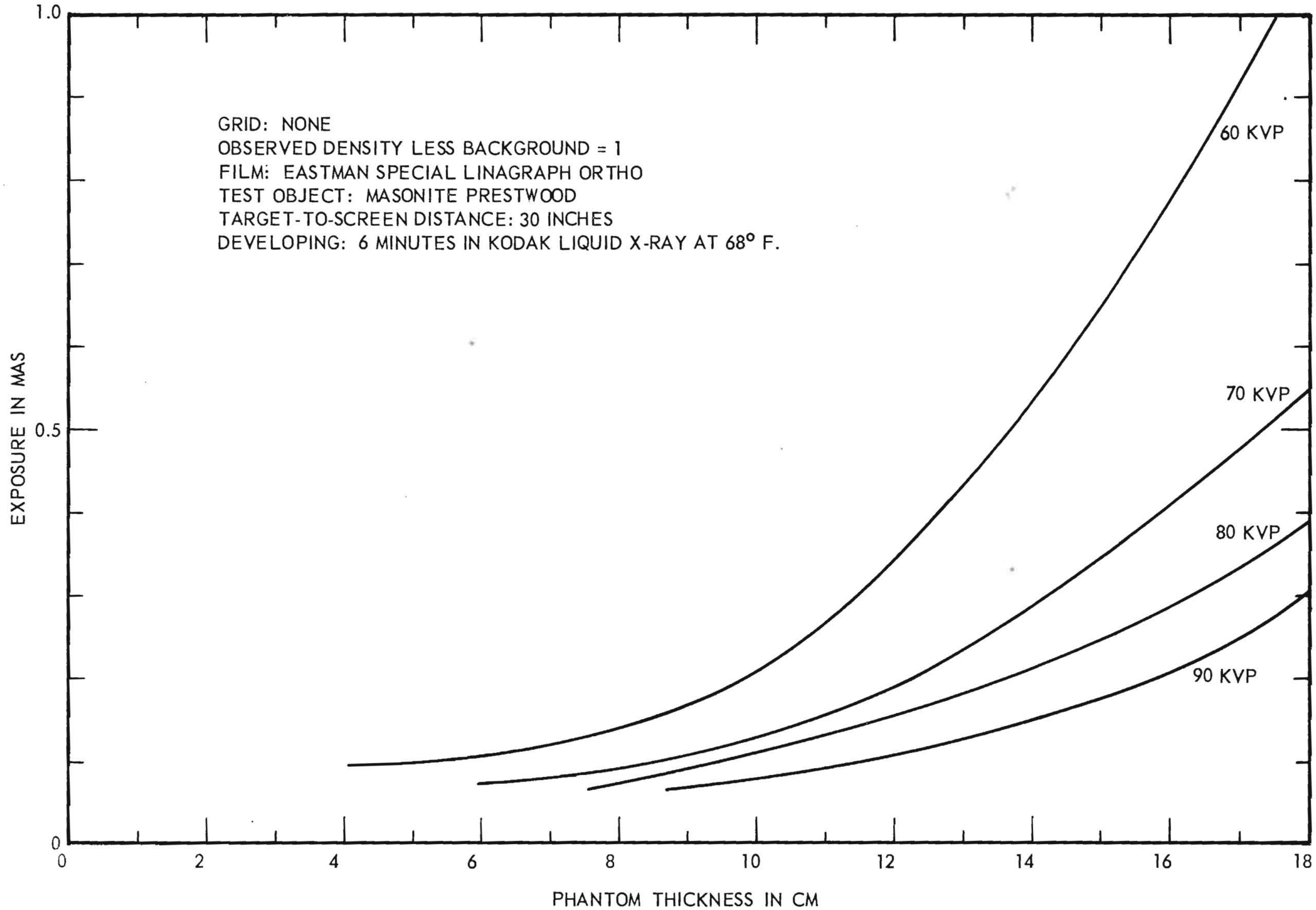


Figure 4. Constant-Density Curves for the Philips Image-Intensifier Tube

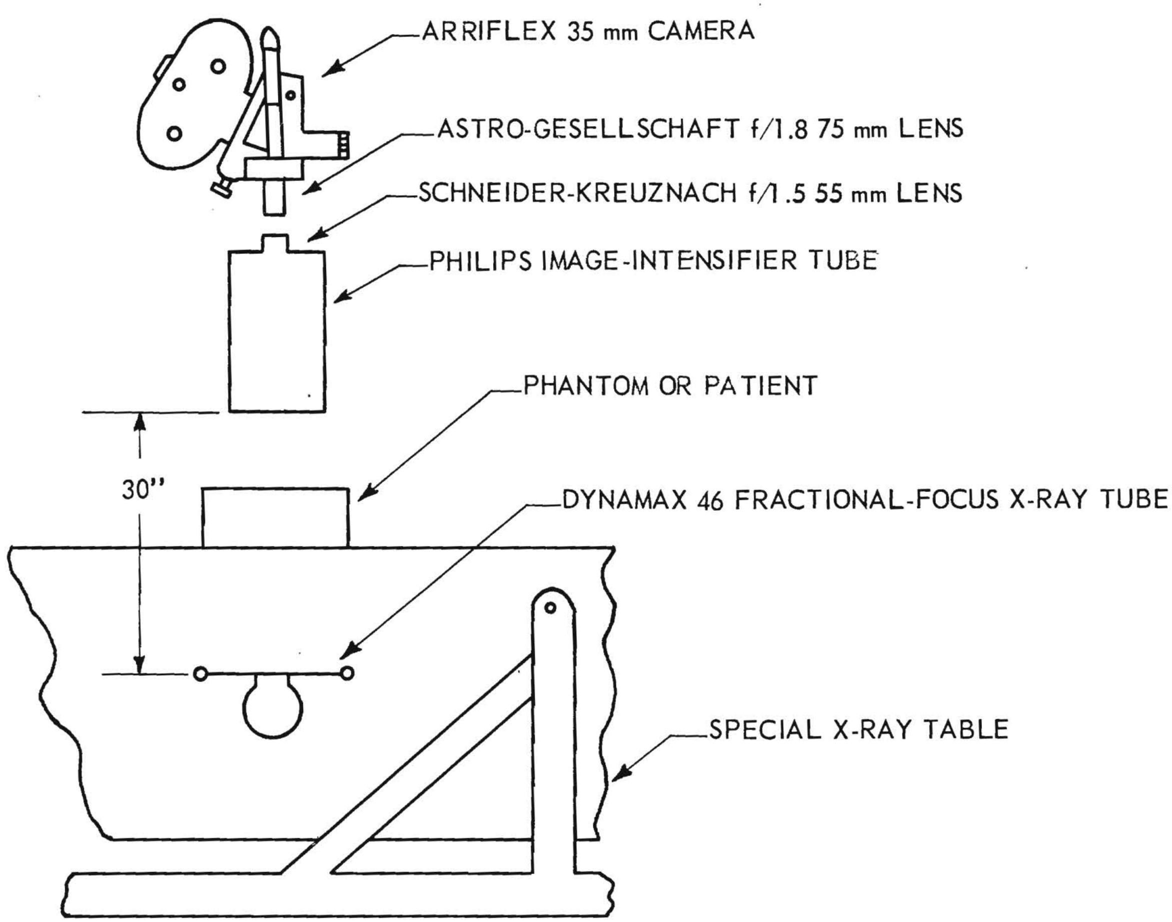


Figure 5. Functional Diagram of the Philips Image-Intensifier Tube

Resolution measurements similar to those for the nonelectronic system were made. Preliminary results indicate resolution very close to that of the nonelectronic system.

V. CONCLUSIONS

The constant-density or technique curves for the nonelectronic system and for the system using the Philips image intensifier tube are presented in this report. However no detailed comparison will be attempted until similar data is available for the Westinghouse image intensifier tube system. Preliminary resolution data for one type of test object is presented for the nonelectronic and the Philips tube. The use of a slower film with the electronic systems should improve the resolution, but would require a larger MAS; the exposure increasing approximately inversely as the ratio of film speeds.

VI. PROGRAM FOR THE NEXT INTERVAL

Further studies of resolution will be made for the Philips image-intensifier tube. A program of clinical evaluation will be started using the Philips tube system, as cases come up, and the angiocardiographic studies on dogs will be continued.

The Westinghouse Electric Company has indicated that it plans to ship a replacement image intensifier tube during the month of September. When this tube becomes available, the major emphasis of the project will be to obtain technique curves and resolution data for this tube so that a comparison of all three systems may be made.

VII. PERSONNEL

The personnel engaged on this project during the period covered by this report were:

Name	Position	Approximate Hours Worked
Brown, J. L.	Assistant Research Physicist	20
Cerney, J. C.	Assistant Research Engineer	80
Simpson, W. C.	Research Associate	130
Williamson, A. E.	Project Director	260
Youmans, H. D.	Technical Assistant	500

Respectfully submitted,

Arthur E. Williamson
Project Director

Approved:

for
J. E. Boyd, Chief
Physical Sciences Division

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY REPORT NO. 7

PROJECT NO. A-203

RESEARCH ON ELECTRONIC CINÉFLUOROGRAPHY

- o - o - o -

CONTRACT NO. DA-36-039-sc-64615
DEPARTMENT OF THE ARMY PROJECT NO. 3-99-04-052
SIGNAL CORPS PROJECT NO. 195B

- o - o - o -

DECEMBER 15, 1956

PLACED BY THE U. S. ARMY
SIGNAL CORPS ENGINEERING LABORATORIES
FORT MONMOUTH, NEW JERSEY

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY REPORT NO. 7

PROJECT NO. A-203

RESEARCH ON ELECTRONIC CINÉFLUOROGRAPHY

by

ARTHUR E. WILLIAMSON

OBJECT: To determine diagnostic suitability of electronic cinéfluorography

PLACED BY THE U. S. ARMY
SIGNAL CORPS ENGINEERING LABORATORIES
FORT MONMOUTH, NEW JERSEY

SEPTEMBER 15 to DECEMBER 15, 1956

TABLE OF CONTENTS

This report contains 9 pages

I. PURPOSE

The purpose of this project is to provide information regarding the suitability of electronic image amplification in cinefluorography. The project consists of an experimental study of commercially available electronic-image-amplifying devices, which will be used in a system incorporating a motion picture camera for recording the image formed on a fluorescent surface by an X-ray beam.

The work is divided into four principal tasks as follows:

(A) the evaluation of nonelectronic cinefluorography to obtain basic information on contrast, exposure factors, detail and overall system efficiency;

(B) the evaluation of electronic cinefluorography to determine which diagnostic procedures are possible with image amplification and to correlate this information with information obtained in Task A;

(C) the fabrication of a laboratory model for cinefluorography using an image-amplifying tube;

(D) the development of accessory items which would be useful in analyzing film results if time and funds permit.

II. ABSTRACT

Tests with the Philips image amplifier tube have been completed. The Westinghouse image amplifier tube is undergoing tests. A report on the work being done with patients is given. The General Electric photoconductive pickup tube system is discussed. The General Electric Company is consigning one of their systems to Emory for use in an evaluation and testing program. Whether the system will be received in time to be considered under this project is not now known.

III. CONFERENCES

On November 8 and 9 Mr. A. E. Williamson and Mr. H. D. Youmans visited the Signal Corps Engineering Laboratories at Fort Monmouth, New Jersey. They were joined on November 9 by Dr. H. S. Weens. Other personnel associated with the ensuing conferences and tests were: Dr. Ralph Sturm, Mr. R. B. Stevenson, and Mr. Bud Hudgins of the Friez Instruments Division, Bendix Aviation Company; and Mr. Joseph DeClerk and Mr. Lou Feller of the Signal Corps Laboratories. The purpose of the visit was to make tests with the Lumicon system similar to tests which have been conducted with the image intensifier tubes. The special test object, which was designed to determine the minimum resolvable vein when the vein contained a contrast media, was carried to the base hospital at Fort Monmouth where the tests were conducted. The results of these tests showed that the Lumicon system could resolve the 0.862 mm tube when it contained 35 percent Diodrast and was suspended at 10 cm depth in 20 cm of water. By comparison, the Philips image intensifier tube system can resolve the 0.609 mm tube under similar conditions. The Lumicon results are consistant with Dr. Sturm's predicted theoretical resolution of about 0.8 mm.

Dr. Weens and Dr. R. H. Rohrer of the Emory University School of Medicine attended the meeting of the Radiological Society of North America in Chicago during the week of December 3. While at the meeting they saw demonstrated the photoconductive X-ray pickup tube which the General Electric Company has developed. This system converts X-radiation directly to an electrical output which can then be amplified and presented on a television screen, whereas the image amplifier tubes which this project has studied convert X-radiation to light then to electrical signals. Although the General Electric system is still in the development stage, Drs. Weens and Rohrer were very favorably impressed with its possibilities. Discussions with General Electric lead to an agreement whereby General Electric plans to consign one of their development instruments to Emory University for tests and evaluation. Dr. Weens is very anxious to compare the photoconductive system with the image amplifier tube systems. The special X-ray table which was built on this project is ideally suited for use with that system.

The General Electric system has an 8 inch diameter viewing area, which could be enlarged on future models as the technique for preparing the photoconductive surfaces is improved. The efficiency of this system is not known at present. However the fact that the General Electric system is direct, no intermediate conversion to light, gives some hope that it could be made more efficient than the other systems. No date has been given for the delivery of the instrument, but it is hoped that it will be received in sufficient time to be considered under this project.

IV. FACTUAL DATA

A. Task A. Evaluation of Nonelectronic Cinefluorography

The nonelectronic system is effectively being rebuilt by the Engineering Experiment Station under a contract from the Department of Radiology, Emory University Medical School. Georgia Tech is furnishing a Mitchell camera movement which is to be modified to accept the Wray lens used in the present system. A new light box has been built which can be used to photograph a patient in either the horizontal or vertical position. Two fluorescent screens will be used, one mounted in the end of the box, the other in the top. By inserting a mirror in the box, the screen in the top is seen by the camera. Without the mirror the screen in the end of the box is seen. The mirror is inserted by folding it down from its mount in the top of the box. A new support mechanism for the light box and camera is also being built. This mechanism will raise and lower the system so that various parts of a patient can be studied. The new system will be completed about the first of January.

In the meantime, the old system is still operative except for continuing malfunctions of the Cunningham camera. In spite of the difficulties with the camera, the system has been used on several patients where motion sequences were desired and where the limited viewing area of the intensifier tubes prohibited their use. Four of the patients had heart ailments which required that the entire heart be seen at one time. One of the patients had a "trick" knee. A series of films showed the difference in action between the injured knee and the action of a normal knee. Three tubercular patients were photographed, along with a normal patient to obtain a film for use on a local television station in their Christmas Seal campaign. In all, eighteen patients were studied with the conventional system during the period covered by this report.

B. Task B. Evaluation of Electronic Ciné fluorography

The resolution studies with the Philips image amplifier tube have been concluded. The results of these studies will be compared with the resolution data on the Westinghouse image amplifier tube and with the resolution data on the nonelectronic system in the final report.

The Philips image amplifier tube system was used on four patients during this report period. Three of the patients had abnormal joints, two elbows, one wrist. The fourth patient had an abnormal larynx.

During the past year numerous normal and abnormal larynx have been studied. This work is being incorporated in a paper to be given at the September meeting of the American Roentgen Ray Society.

The Westinghouse image amplifier has been used to obtain a film strip on a patient with a calcified heart tumor. As the occurance of a tumor in the heart, especially one of this large a size, is rare, great interest has been shown in this film by the medical profession. Present plans call for combining the X-ray film and a film of the operation to remove the tumor to make up a movie which will be shown at several medical meetings. The proceedings of one of these meetings, the New York meeting of the Tumor Society in April, will be published and the X-ray film will be used as an illustration in the paper.

V. CONCLUSIONS

The delay in delivery of the Westinghouse image amplifier tube has made it impossible to complete the evaluation of that tube before the end of the period covered by this report. Therefore this report is brief, the discussion of the relative merits of the systems being postponed until the next report, which will be the final report.

VI. PROGRAM FOR THE NEXT INTERVAL

The constant-density and resolution studies on the Westinghouse image amplifier system will be concluded. The program of patient examinations will be continued. The modified nonelectronic system will be installed and checked out. Preparation of the final report and an article for one of the medical journals on the work done on the project will commence as soon as all the data is available.

If the General Electric photoconductive pickup tube and its related system are received in time, and evaluation of that system will be made and included in the final report.

VII. PERSONNEL

The personnel engaged on this project during the period covered by this report were:

Name	Position	Approximate Hours Worked
Brown, J. L.	Assistant Research Physicist	10
Cerney, J. C.	Assistant Research Engineer	10
Simpson, W. C.	Research Associate	130
Williamson, A. E.	Project Director	230
Youmans, H. D.	Technical Assistant	500

Respectfully submitted,

Arthur E. Williamson
Project Director

Approved:

Physical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
Atlanta 13, Georgia

GIT / EES Report: A203 / T1
15 March 1957

FINAL REPORT
on
RESEARCH ON ELECTRONIC CINEFLUOROGRAPHY

by
Arthur E. Williamson

CONTRACT No. DA-36-039-sc-64615
Department of the Army - Project No. 3-99-04-052
Signal Corps Project No. 195 B

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
Atlanta 13, Georgia

GIT / EES Report: A203 / T1
15 March 1957

FINAL REPORT
on
RESEARCH ON ELECTRONIC CINEFLUOROGRAPHY

by
Arthur E. Williamson

CONTRACT No. DA-36-039-sc-64615
Department of the Army - Project No. 3-99-04-052
Signal Corps Project No. 195 B

Submitted:

Arthur E. Williamson
Project Director A203

Approved:

J. E. Boyd, Associate Director
Engineering Experiment Station

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

I. PURPOSE

The purpose of this project was to provide information regarding the suitability of electronic image amplification in cinéfluorography. The project consisted of an experimental study of commercially available electronic-image-amplifying devices, which were used in a system incorporating a motion picture camera for recording the image formed on a fluorescent surface by an X-ray beam.

The work was divided into three principal tasks:

(A) the evaluation of nonelectronic cinéfluorography to obtain basic information on contrast, resolution of detail, exposure factors and overall system efficiency;

(B) the evaluation of electronic cinéfluorography to obtain basic information as above and also to determine which diagnostic procedures are possible with image amplification;

(C) the fabrication of a laboratory model for cinéfluorography using an image-amplifying tube.

II. ABSTRACT

A description of the apparatus and procedures used in the evaluation of image-intensifying tubes is given.

Special problems occurring in the evaluation program due to the different sizes of the output phosphors of the tubes are noted.

A special test object for determining the diameter of the minimum resolvable vein located at a given depth in a body is described and results show that the image-intensifier tubes have resolution characteristics equal to or better than the other systems tested. For a 20-cm water phantom and a Diodrast concentration of 35 percent, the Philips tube system could resolve a tube of inside diameter 0.58 mm; the Westinghouse tube system, 0.76 mm. Among the other systems tested were the Bendix-Friez Lumicon (resolution under the same conditions as above, 0.76 mm); the Westinghouse Fluorex (resolution, with accommodation, 0.58 mm, without, 0.76 mm); conventional fluoroscopy (resolution greater than 1.77 mm, the largest tubing available); and the General Electric TV-X direct-conversion system. The resolution of this last system is given as 0.58 mm for a 10-cm phantom because of limitations of the X-ray source.

The need for a mathematical expression relating the X-ray parameters to the radiographic effect is discussed.

Amplification factors for the image-intensifier tube systems are defined and given. Practically, these amplification factors represent the factors by which the required X-ray dose to a patient may be reduced. For the systems discussed in the text, which represent systems that are optimum at the present state of the art, the Philips tube system has an average amplification factor of 11, compared to conventional cinéfluorography, and the Westinghouse tube system an average amplification factor of 5. These values are for optical magnifications such that the maximum area of a 35-mm film frame is used in each case. If the relative optical amplification for each system were the same, the image tubes would appear much better in the comparison.

The desirability of making the special X-ray table and related equipment available to Emory University, or a similar organization, for continued clinical work is noted.

I. PURPOSE

The purpose of this project was to provide information regarding the suitability of electronic image amplification in cinéfluorography. The project consisted of an experimental study of commercially available electronic-image-amplifying devices, which were used in a system incorporating a motion picture camera for recording the image formed on a fluorescent surface by an X-ray beam.

The work was divided into three principal tasks:

(A) the evaluation of nonelectronic cinéfluorography to obtain basic information on contrast, resolution of detail, exposure factors and overall system efficiency;

(B) the evaluation of electronic cinéfluorography to obtain basic information as above and also to determine which diagnostic procedures are possible with image amplification;

(C) the fabrication of a laboratory model for cinéfluorography using an image-amplifying tube.

II. ABSTRACT

A description of the apparatus and procedures used in the evaluation of image-intensifying tubes is given.

Special problems occurring in the evaluation program due to the different sizes of the output phosphors of the tubes are noted.

A special test object for determining the diameter of the minimum resolvable vein located at a given depth in a body is described and results show that the image-intensifier tubes have resolution characteristics equal to or better than the other systems tested. For a 20-cm water phantom and a Diodrast concentration of 35 percent, the Philips tube system could resolve a tube of inside diameter 0.58 mm; the Westinghouse tube system, 0.76 mm. Among the other systems tested were the Bendix-Friez Lumicon (resolution under the same conditions as above, 0.76 mm); the Westinghouse Fluorex (resolution, with accommodation, 0.58 mm, without, 0.76 mm); conventional fluoroscopy (resolution greater than 1.77 mm, the largest tubing available); and the General Electric TV-X direct-conversion system. The resolution of this last system is given as 0.58 mm for a 10-cm phantom because of limitations of the X-ray source.

The need for a mathematical expression relating the X-ray parameters to the radiographic effect is discussed.

Amplification factors for the image-intensifier tube systems are defined and given. Practically, these amplification factors represent the factors by which the required X-ray dose to a patient may be reduced. For the systems discussed in the text, which represent systems that are optimum at the present state of the art, the Philips tube system has an average amplification factor of 11, compared to conventional cinéfluorography, and the Westinghouse tube system an average amplification factor of 5. These values are for optical magnifications such that the maximum area of a 35-mm film frame is used in each case. If the relative optical amplification for each system were the same, the image tubes would appear much better in the comparison.

III. INTRODUCTION

A. Purpose of Image-Intensification in Radiography

Basically, the purpose of any image-intensifying device is to enable as much information as possible to be extracted from the fluorescent image of an object, for a given X-ray dose. For ordinary fluoroscopy, the amount of small-object detail in the screen depends on the X-radiation absorbed by the screen. The amount of radiation absorbed is closely related to the dose to which the patient is exposed. The observer is unable to utilize all the detail in the screen, however, because of the limited ability of the eye to retain detail. The usual arrangement is optically inefficient also, only a small fraction of the light emitted by the fluorescent screen reaching the retina of the observer's eye. Likewise in miniature radiography, an appreciable light loss occurs in the optical link, in this case, due to the small aperture of the camera lens. For a typical system, only about one percent of the light leaving the screen reaches the film.* Full-size radiography using double-emulsion film and intensifying screens is much better in this respect, the direct contact between the film and the intensifying screens preventing loss of light.

Thus a main purpose of an image-intensifying device is to compensate for the light energy loss in the optical system between the fluorescent screen and the light detector.

The image-intensifying tube considerably increases the efficiency of the system, for a given X-ray dose, when this system is compared with miniature radiography. However, when compared to full-size radiography, the image intensifier offers only secondary advantages. These are: (1) the X-ray dose to the patient is reduced and (2) cinématography, or the production of X-ray motion pictures, is practical.

- - - - -

* M. C. Teves, Philips Technical Review 17, 3, 69-71 (1955).

B. History of the Present Project

The original request for a proposal for research in cinéfluorography was received in September 1954. The Georgia Tech Research Institute was awarded the contract and the technical phase of the program commenced on February 15, 1955. Initially Mr. John H. Tolan was assigned as project director. He was assisted by Mr. John L. Brown, Mr. Ralph Johnson and Mr. John Fields. In September of 1955, Mr. Johnson and Mr. Fields left the project and Dr. W. C. Simpson, Assistant Professor of Physics at Georgia Tech, joined the project as a quarter-time consultant. Mr. Harry D. Youmans, a physics student at Emory University, was hired about this same time as a part-time Technical Assistant. Mr. Youmans' previous experience as a service representative of the X-ray department of the Westinghouse Electric Corporation has been invaluable.

When Mr. A. E. Williamson joined the staff of the Engineering Experiment Station in September 1955, he was assigned part time to the project. Mr. Brown has continued to assist the project with its optical problems.

When Mr. Tolan terminated his employment at Georgia Tech in May 1956, Mr. Williamson assumed the duties of project director.

The original contract period was for one year, February 15, 1955, to February 15, 1956. Because of difficulties in obtaining satisfactory image-intensifier tubes and because of the desire to expand the clinical phase of the program, the contract was renewed for a second period, terminating March 15, 1957.

The experimental program has been conducted in space provided by the Department of Radiology of the Emory University Medical School. This department has also supplied the conventional cinéfluorography system for comparison with the image-intensifier tubes. The assistance and advice of the personnel at Emory University have been invaluable. Dr. H. S. Weens, Chairman of the department, was especially helpful to the project by making his own services available when needed as well as for furnishing space in his department for the experimental program and for furnishing patients for the clinical program.

IV. EXPERIMENTAL PROGRAM

In order to obtain a reference for comparison, a program of tests was conducted with the conventional cinéfluorography system which the Department of Radiology of the Emory University School of Medicine had constructed. Some difficulties were encountered with this system due principally to camera malfunctions. Recently this system has been considerably modified and in its present form, functions reliably. A detailed description of this system is given later.

The image-intensifier tubes are bulky, heavy items, weighing about 50 pounds. Because of their bulk and weight, a sturdier supporting mechanism was required than was commercially available at the time. The decision was made to build a complete table, X-ray tube and image-amplifier tube assembly, rather than to buy a commercial table and modify it for this purpose. The first cost estimate indicated that this would be a much less expensive approach; however, as it turned out the costs might have been less if a commercial table had been purchased and modified.

It is believed that a significant contribution was made to the X-ray-table-design art in that the special table demonstrated the feasibility of using non-hardened ways with nylon tired roller bearings, instead of hardened ways and steel-bearings generally used. This represents a considerable savings in the cost of construction of a table. Features of the special X-ray table are discussed further below.

In the field of optics and photography, resolution may be defined as the number of uniform lines or obstructions per unit length which can just be distinguished as separate lines. These lines may be uniformly spaced with the width of the spaces equal to that of the obstructions. In radiography, resolution is used rather loosely to mean either the number of evenly spaced obstructions per unit distance which can just be distinguished or, more often, to mean the smallest object which can be discerned against a given background. Furthermore, in optics, the lines are black and the spaces are white. In radiography this would compare to lead obstructions and air spaces, a situation which has little meaning in a study of the body. The radiologist is interested in seeing a particular organ or part of the body embedded in the rest of the body. In optics the word "contrast" would be more descriptive of what the radiologist seeks. This would correspond to trying to resolve a group of lines of one shade of gray, with the spaces a slightly different shade of gray.

For the purposes of this report resolution will be used in the sense that the radiologist uses it. The most useful resolution determination is one which stimulates conditions within the body. Many materials are used to simulate tissue. Three major factors to be considered in the selection of a material are: (1) bulk density, (2) electron density and (3) effective atomic number. Some common materials for which the properties listed above are similar to tissue are water, Masonite Prestwood, Plexiglas and rice*. Water is often used because it is readily available and instruments may be inserted and moved around within the test object. Plexiglas is often formed into a container for water. Rice can be sewed into specially shaped bags to simulate particular portions of the anatomy. Test objects constructed by laminating thin sheets of Masonite Prestwood are used to simulate parts of the body of more complex shape.

While a more sophisticated approach has been taken by some groups** in the construction of test objects (or phantoms) for special purposes, a simple approach will yield useful results in many cases. For example, a test object to simulate veins within the body can be very simply constructed. Such a device is described in a later section.

A. Description of Apparatus

1. Conventional System

The conventional or nonelectronic system is shown diagrammatically in Figure 1, and photographically in Figures 2 and 3. This system utilizes a

- - - - -

* See, for example, Spiers, F. W., "Scattering and Absorption of Common Phantom Materials." British Journal of Radiology (1943).

** See, for example, Splettstosser, H. R. and Seemann, H. E., "A Phantom for Physical Studies in Chest Radiography." Radiology 64, 1, 114 (1955).

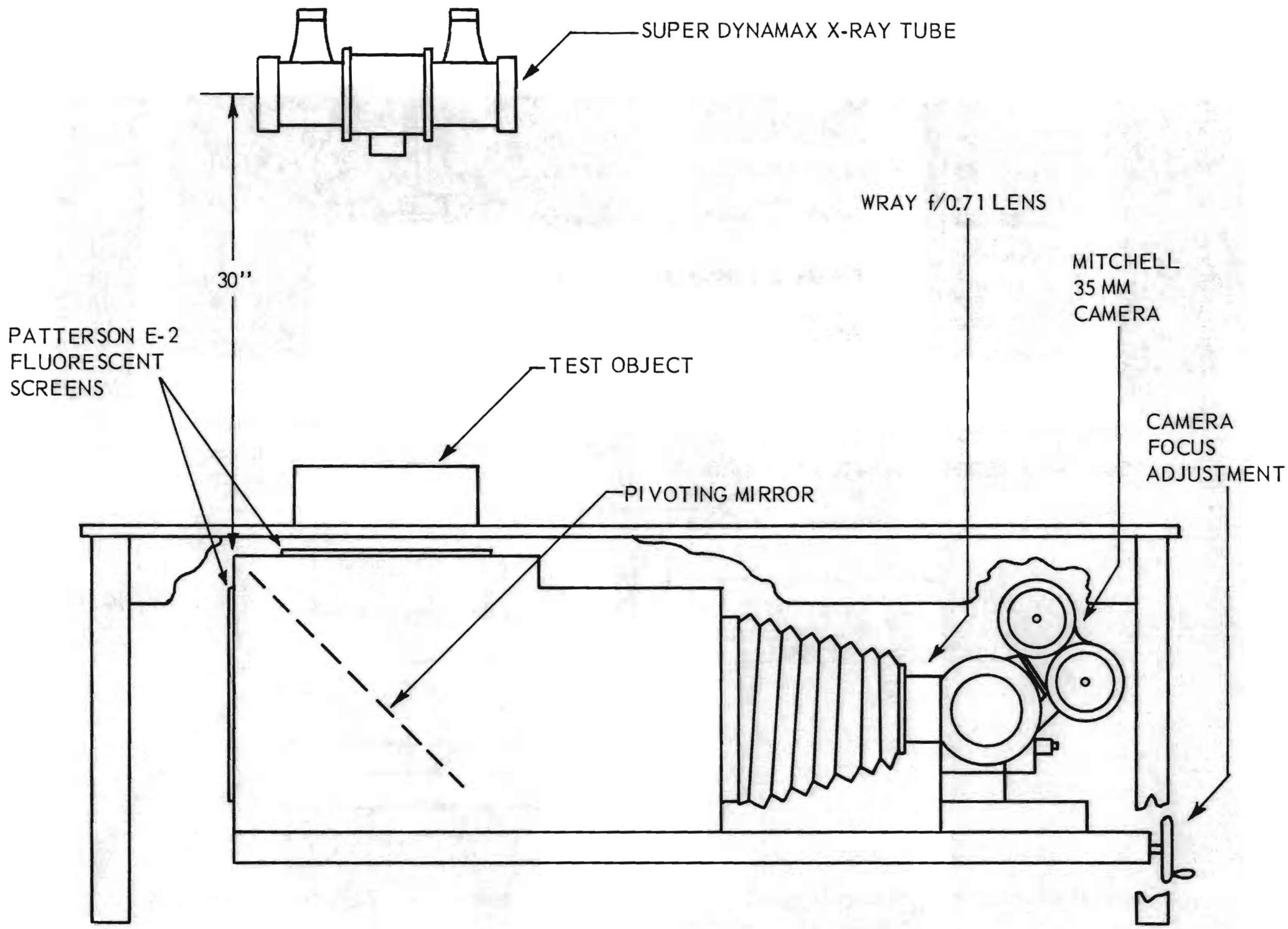


Figure 1. Functional Diagram of Conventional Cinéfluorography System.

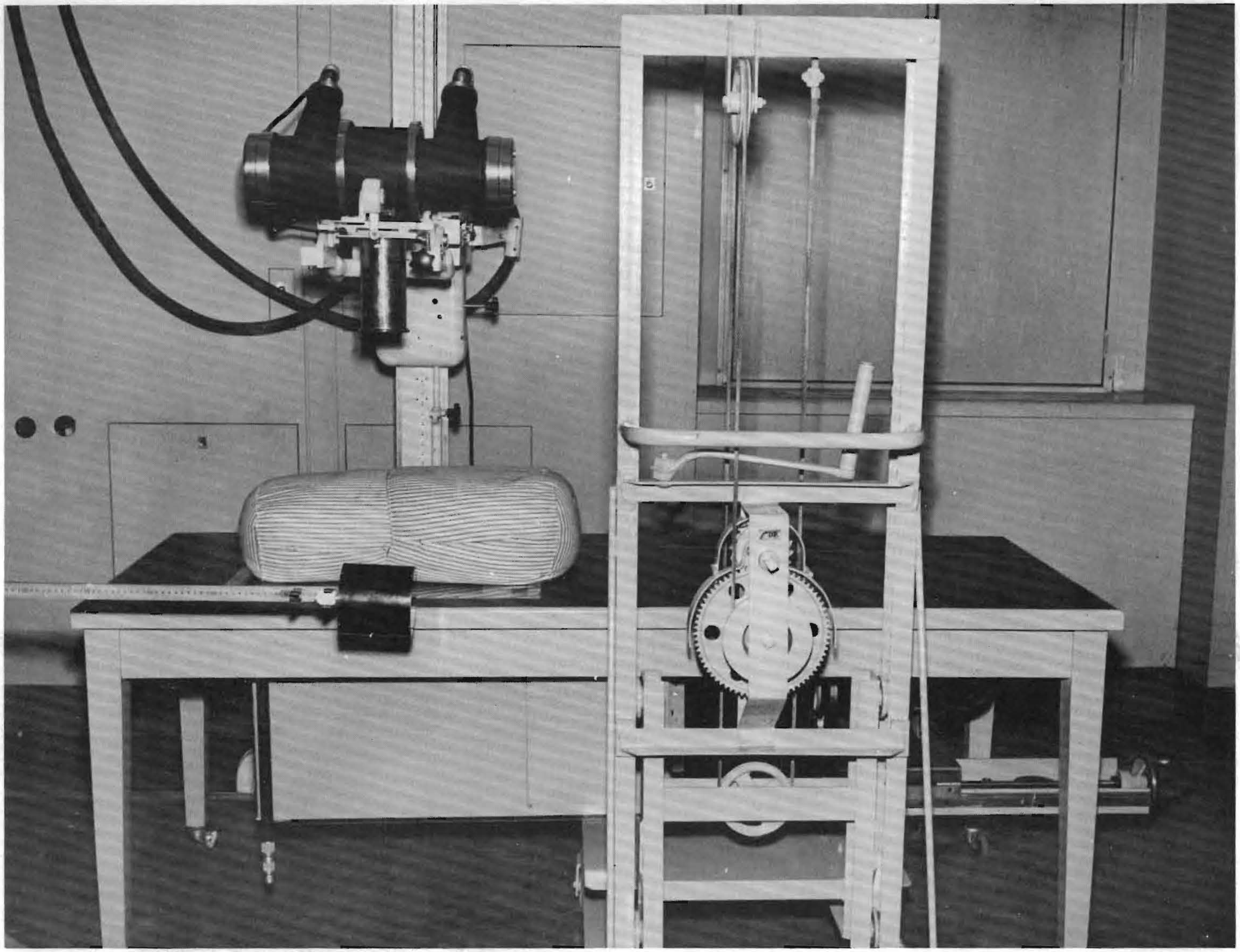


Figure 2. Conventional Cinéfluorography System with Setup for Determining Scattered Radiation.

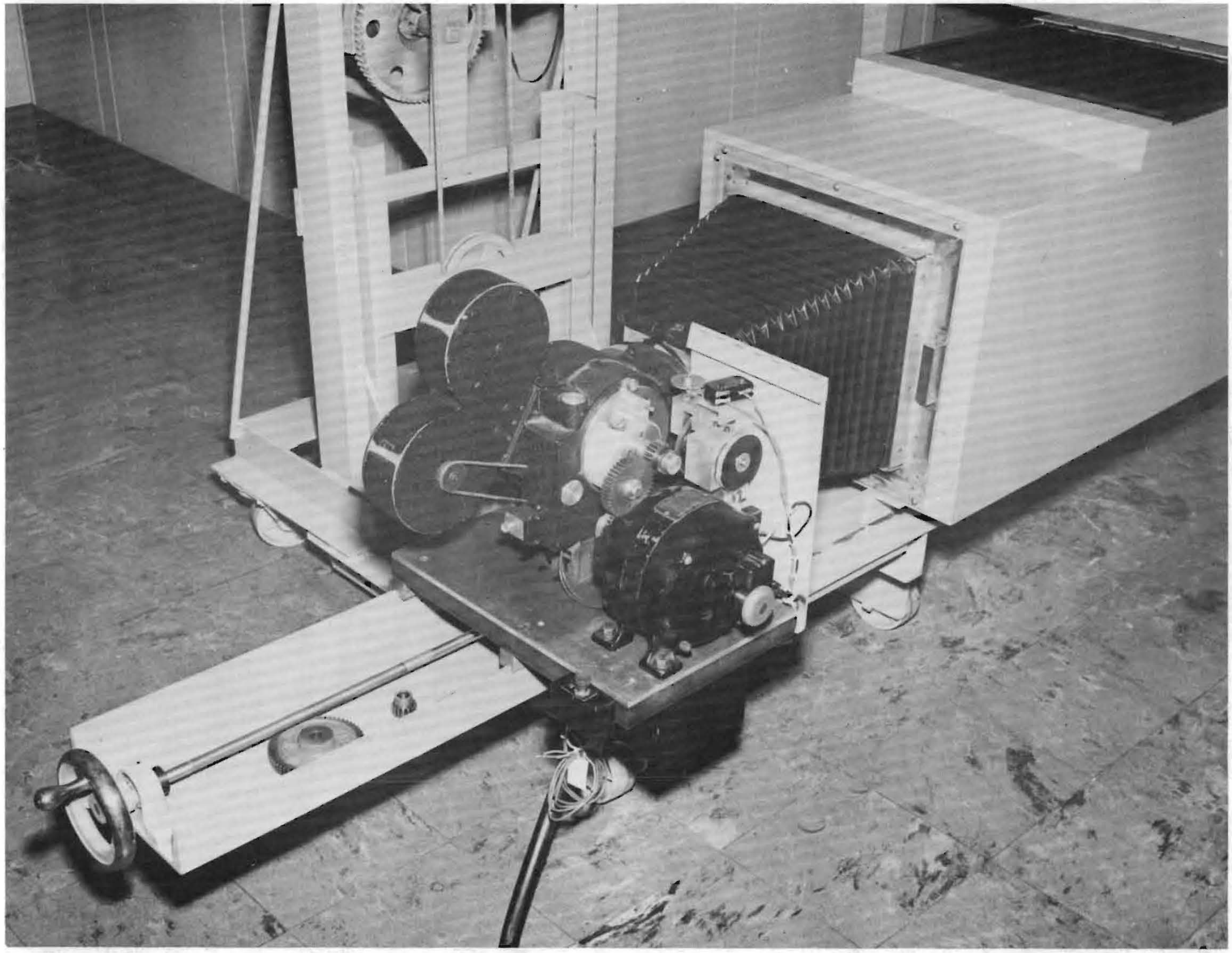


Figure 3. Camera and Camera-Drive Mechanism for Conventional Cinéfluorography System.

Machlett "Super Dynamax," double-focusing X-ray tube. The effective focal-spot sizes are 1 mm and 2 mm. Originally the tube was mounted on a side-rail tube-stand, but the lack of rigidity of this stand necessitated the change to a floor-to-ceiling type of tube-stand, as shown in the picture.

The same high voltage generator is used for both the conventional and the image-amplifier tube systems. This generator supplies a peaked voltage, and when operated from a 60-cycle line, it gives 120 pulses per second to the X-ray tube. The maximum ratings of this generator are 100 kilovolts-peak and 200 milliamperes average. A high voltage switch within the transformer box switches the output to the selected X-ray tube.

A pair of TX45-S thyratron tubes control the current to the X-ray transformer. These tubes are controlled by the exposure-initiating circuit, which makes it possible to switch the X-ray tube power on and off rapidly, making possible the operation described below.

Two Patterson E-2 fluorescent screens are provided. One is mounted in the end of the light box for direct cinéfluorography of a standing patient. The other is mounted in the top of the light box for study of lying-down patients and uses a front-surface mirror at 45 degrees to reflect the image into the camera. The optical path-length from the screen to the film is the same in both cases. The mirror folds up against the top of the box when not in use. All of the tests discussed here were made using the fluorescent screen in the top of the box, the box being placed under the table as shown in Figure 2.

Originally a 35-mm Cunningham camera was used in this system. This camera had been extensively modified and malfunctioned frequently.

At some time in the past, Georgia Tech acquired two high-speed Mitchell camera movements as surplus property. Arrangements were made to transfer one camera to Emory University, with the condition that it be modified to accept the Wray lens so that it could be used for this work. This was done and the present system, incorporating the Mitchell camera movement, is shown in Figure 3. In the case of the Mitchell, as well as the Cunningham camera, synchronization of the film transport mechanism with the X-ray pulses is achieved by a cam-operated microswitch. The Mitchell camera has an electrical interlock to stop the camera in the event of a film jam.

Two lenses were tested with this system: a Bausch and Lomb f/0.9 and a Wray f/0.71. The Wray lens was selected for the subsequent tests with this system because the B and L lens had a curvature of field which limited its use at 35 mm.

The camera is driven by an 1800-rpm synchronous motor through a gear system which permits framing speeds of 7.5, 15 and 30 frames per second. The cam which operates the mechanism to synchronize the X-ray pulses with the film transport is driven by this same gear system. A second cam-microswitch circuit is driven by the gear system to give one-second timing markers to an electrocardiograph and to a small neon bulb in the field of view of the camera, thus synchronizing the electrocardiograph charts and the cinéradiographs.

The drive motor, gear system, and camera are mounted on ways which allow accurate focusing, and a choice of three reduction ratios for field size: 12:1, 16.5:1 and 20.9:1. The 16.5:1 ratio is most commonly employed, since this is very close to the ratio for which the Wray lens was designed, 16:1.

By pulsing the X-rays synchronously with the film-indexing mechanism, it is possible to operate the conventional system without a shutter. This is desirable because the short back-focus of the Wray (and also the B and L) lens would require a before-the-lens shutter and, while this type of shutter has been built, it is complicated and expensive.* The persistance of a fluorescent screen such as the Patterson E-2, which has a very short decay time, has not caused image blurring or carry-over from one frame to the next; at least not to a noticeable degree. The build-up of screen persistence as a result of long exposures is unavoidable without an elaborate quenching device. It is well known that fluorescent lag is dependent upon both the intensity of the exposure and the elapsed time of the exposure. During a long exposure a build-up of intensity has been observed. However, pulsing certainly reduces such build-up.

- - - - -

* Mr. S. Weinberg has such a shutter on his unit at the University of Rochester.

There are several other advantages to synchronously pulsing the X-ray exposure: (1) the X-ray exposure to the patient is reduced, (2) the load on the X-ray tube is lessened and (3) the control thyratrons operate cooler.

The ways which hold the camera and light-box assemblies are mounted on a hoisting device which permits positioning of the light box at any desired height from the floor up to about six feet. This device is basically a fork-lift mechanism with a ratchet and slip-clutch crank. Additional tripod-like extensionable legs are provided to steady the light box in the higher positions.

This system has two primary limitations: (1) there is no provision for visual monitoring of the fluorescent image and (2) the patient is exposed to a relatively large X-ray dose during a typical examination. While it is not absolutely necessary to monitor the fluorescent screen, it would be convenient during certain procedures, such as heart catherizations.

As an example of the dose received by a patient consider the following: it is desired to study the lower abdomen of a patient. An average abdomen is 20 cm thick. To obtain a film with an average density of one would require a "technique" of 90 KVP and 200 MA.* At 90 KVP and a film-to-skin distance equal to 12 inches, the roentgen-rate in air is 3.5 r/100 MAS.** An average examination of a body process takes about six seconds. Because the X-ray source is pulsed, only one-fourth of this time is the skin-dose time. So, the skin dose is $(\frac{3.5\ \text{r}}{100\ \text{MAS}})(\frac{6\ \text{sec}}{4})(200\ \text{MA}) = 10.5\ \text{r}$. This is normally considered to be a maximum diagnostic exposure for people who are still in their reproductive years. Thus the usefulness of this system is governed by the required exposure to the patient and by the prognosis of the patient's condition.

- - - - -

* The word technique is used by the medical profession to denote a set of radiographic conditions. For X-ray systems with control panels such as used here, a technique is a particular KVP, MA and S combination. If it is desired, for example, to make a radiograph of an object of a given thickness and density then the proper technique would consist of the KVP, MA and S combination to give the desired average density on the film.

** The meaning of roentgen-rate and the source of the quoted value are given in Section IV-D-3.

2. Special X-Ray Table

As mentioned above, a special X-ray table was designed and constructed for the evaluation of image-amplifier tubes. This table is shown in Figures 4 and 5. It was built for both technical and clinical applications. It may be used in either the vertical or horizontal position. The table is of sufficient length to hold an adult patient. The tower, or carriage assembly, to which the image tube and camera are fastened, has the three conventional directions of motion to permit easy and accurate positioning of the image tube with respect to the desired anatomical part of the patient.

This table is much heavier and more sluggish in operation than most commercially available diagnostic X-ray tables. The weight is the result of an effort to build a system rigid enough to maintain good alignment between the X-ray tube and the image-amplifier tube for all positions of the tube and table.

Original plans called for counterbalancing the table so that it would swing from horizontal to vertical, or vice-versa, with little effort by the operator. Unfortunately, this required the addition of too much weight to the "boot" of the table, so a hand-cranked winch is used to pull the table up to the vertical position or to lower it to the horizontal position. Safety locks are provided at these positions so that the weight of the pivoting portion of the table does not rest on the cables.

The X-ray tube, a Machlett "46" fractional-focus tube, is mounted below the table top and coupled through a yoke to the image-amplifier tube in such a manner that the axes of the primary beam of the X-ray tube and the image-amplifier tube are aligned at all times, irrespective of the amplifier-tube separation. The effective focal-spot sizes of this tube are 0.3 mm and 1.5 mm. It is a conventional under-table type of diagnostic X-ray tube which has a rotating anode. The X-ray-tube-target-to-table-top distance is always 18 inches. The table top is 5/16-inch laminated phenol-formaldehyde, which has been examined with X-rays to assure uniform radiolucency throughout the sheet. The X-ray beam is limited by a brass collimator to a cone just large enough to illuminate the input screen of the image intensifier at a position 12 inches above the table top.

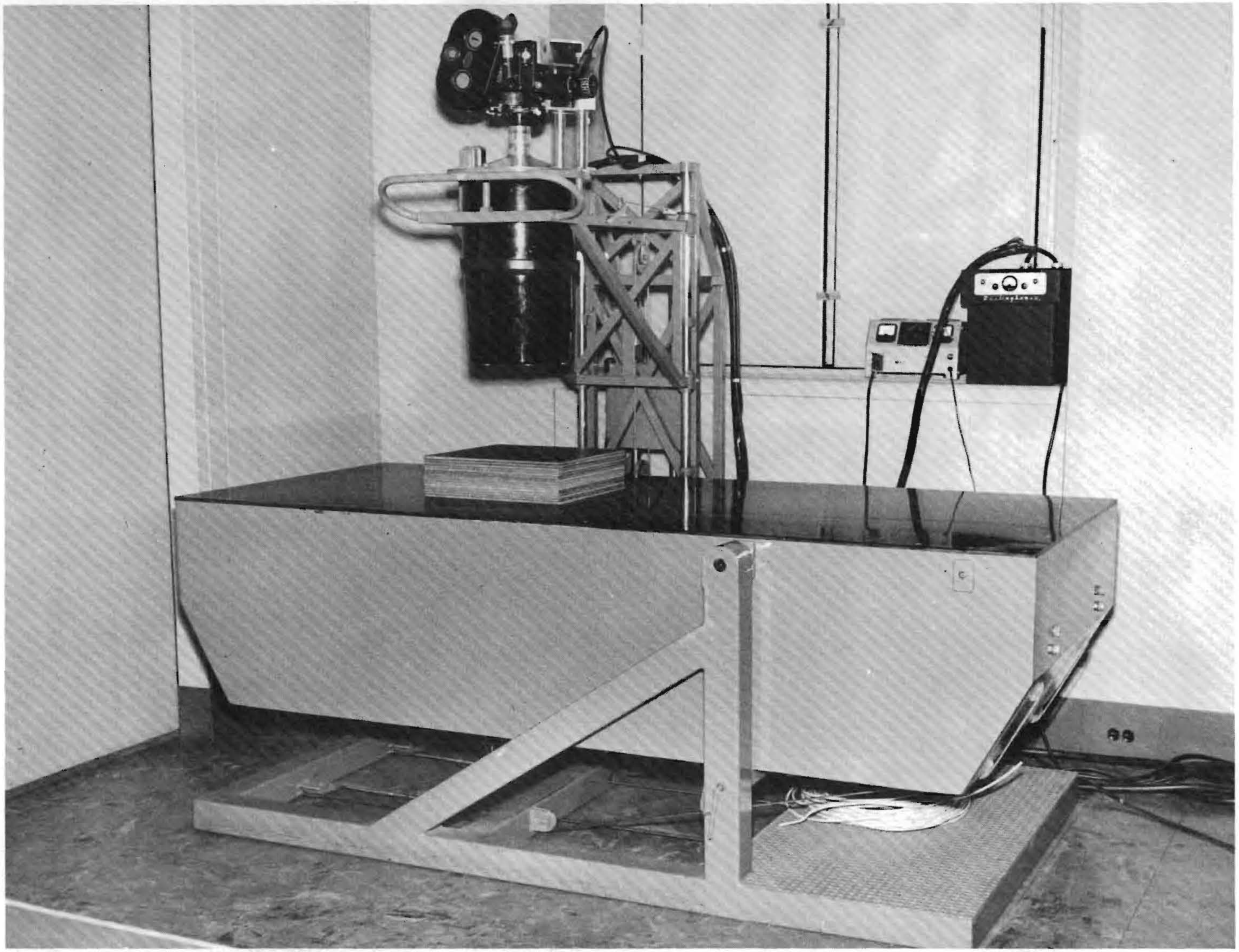


Figure 4. View of Special X-ray Table in a Horizontal Position.

Figure 5. View of Special X-ray Table in a Vertical Position.

One of the innovations of this table is the use of non-hardened ways and roller bearings with nylon sleeves on the moving-tower mechanism. Figure 6 shows one of these assemblies. Previously, hardened ways and steel rollers have been used. The fact that non-hardened material can be used in this application represents a savings in the manufacture of an X-ray table. Some difficulty was evidenced with the first design, which consisted of a single roller bearing with a nylon sleeve around it. The sleeve tended to "walk" off of the bearing. A redesign, replacing the single roller bearing with two bearings and making the nylon sleeve with an internal flange to fit down between the two rollers, remedied this difficulty. Operation of the table for over a year has indicated no difficulty with the redesigned bearing assemblies.

Another feature of the special X-ray table is that its surface when horizontal is several inches lower than commercial tables. This feature is desirable in order that the radiologist may monitor the examination through the Arriflex camera* without standing on an elevated platform.

3. Special Resolution Test-Object

A box approximately 15 inches on a side and 10 inches deep was constructed from 3/16-inch Plexiglas. By filling the box with water to various levels, different body thicknesses could be simulated.

A 1/4-inch plate of Plexiglas was used to mount polyethylene tubing of various inside diameters, as shown in Figure 7. This plate can be suspended at various depths in the box to simulate the location of veins in the body.

B. Description of Image-Amplifier Tube Systems

Each of the image-amplifier tubes considered here, the Westinghouse Electric Corporation tube and the N. V. Philips Gloeilampenfabrieken tube were tested under similar conditions. The X-ray-tube-target-to-fluorescent-screen distances were the same, and the same type optical system was used.

- - - - -

* This camera has a through-the-lens-monitoring system which works from light reflected by a silvered shutter. Thus the use of the monitoring system does not interfere with the operation of the camera or decrease the optical efficiency of the system.

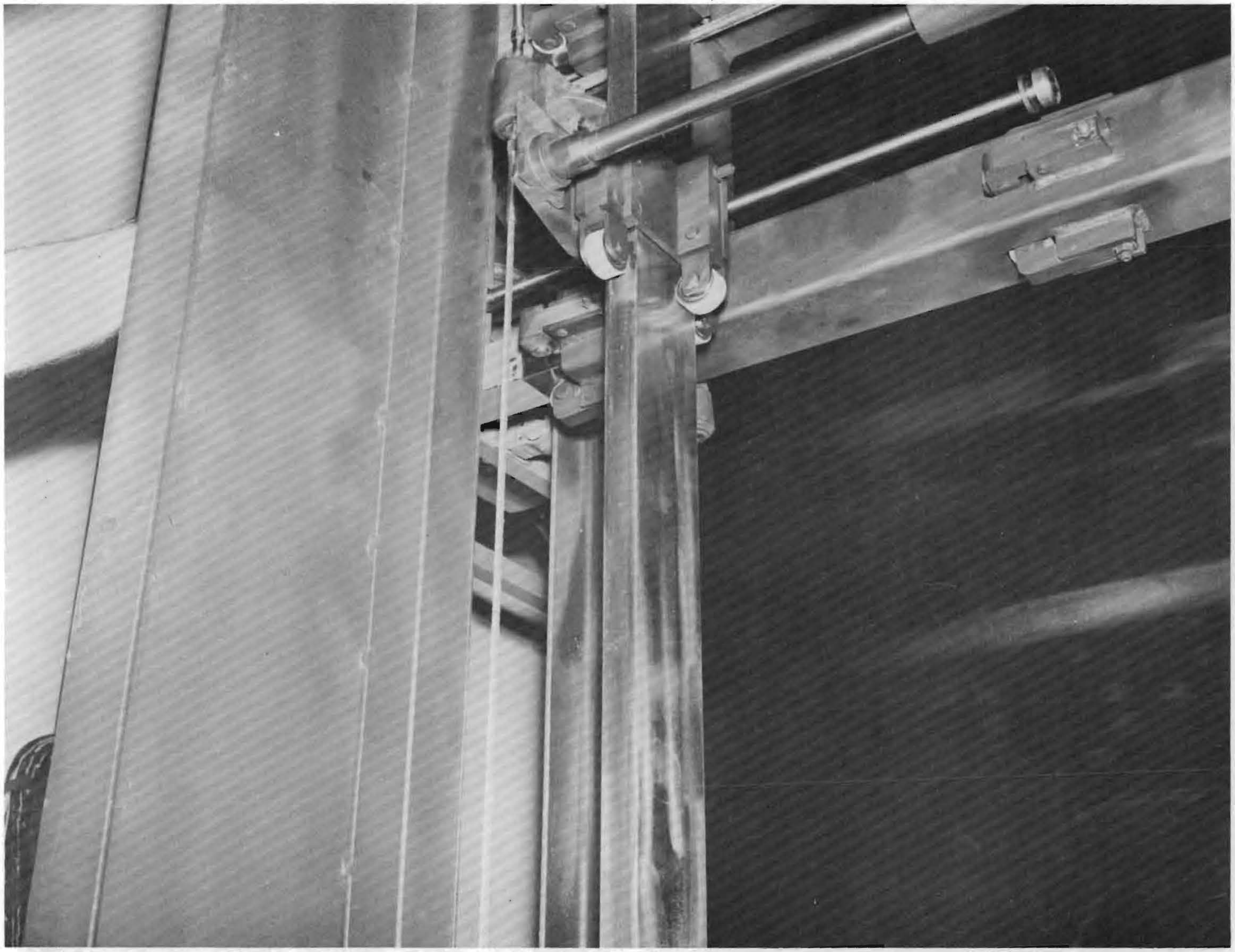


Figure 6. View of Nylon Roller-Bearing Assemblies Used on Special X-ray Table.

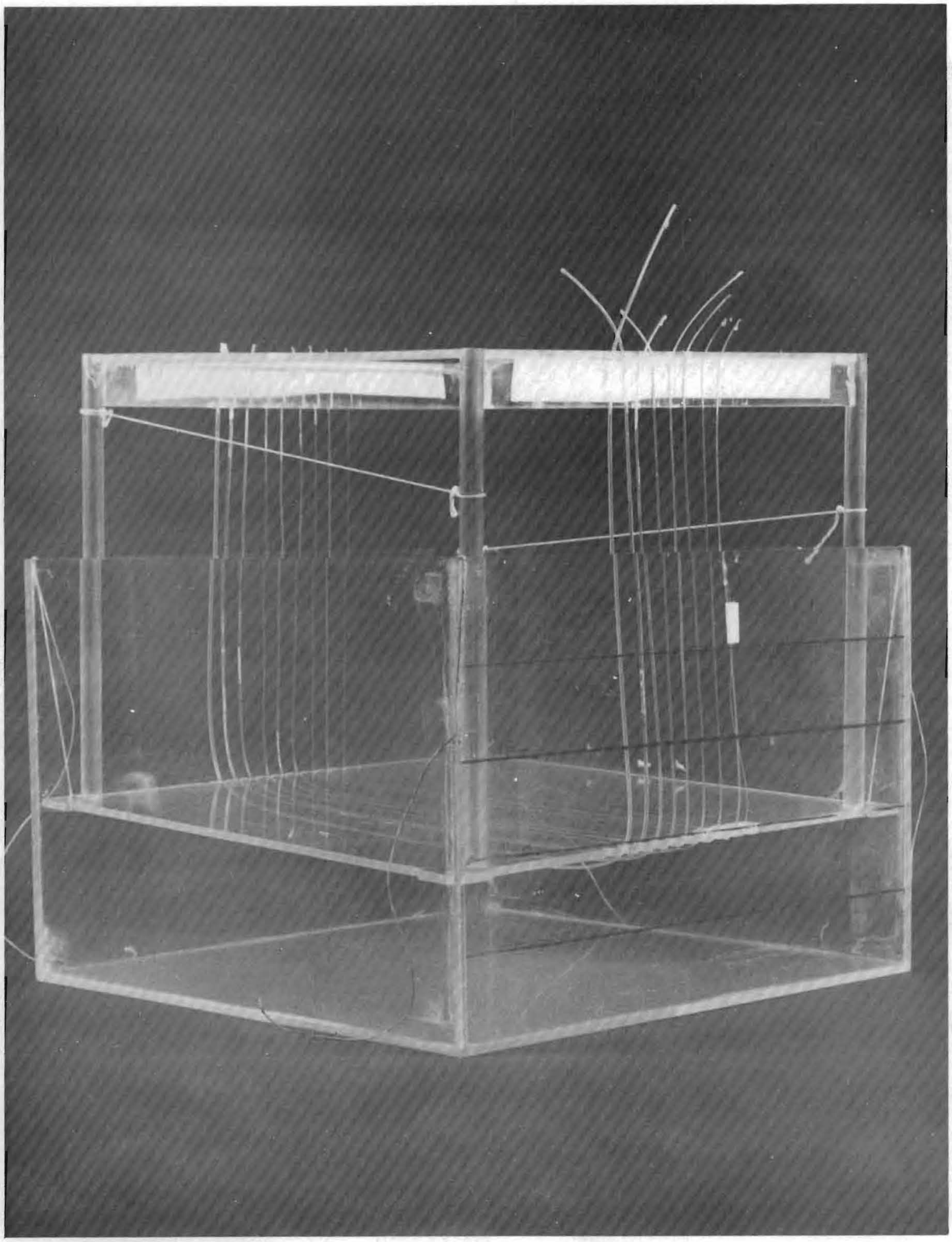


Figure 7. Special Test-Object Used to Simulate Veins in the Body.

This system consisted of a coupling (or projecting) lens to pick up the image of the output screen and focus it at infinity. Then the camera (or taking) lens picked up this image and focused it on the film. With the coupling and taking lenses focused at infinity, the spacing between the two lenses was not critical. A partially silvered mirror could be interposed in the beam if desired, to separate out some of the light for a monitoring system. The use of the Arriflex camera with its through-the-lens monitoring system eliminated the need for an additional monitor in this system.

The Philips tube was equipped with an f/1.5 coupling lens. The Westinghouse tube was not equipped with a similar lens, so an additional support element was required for this system. The use of smaller f-number lenses was considered in order to increase the light transmission to the film. This would not be as beneficial as it seems, however, primarily because of the small size of the image and object with which the system works. The output phosphor of the Westinghouse tube has a diameter slightly less than one inch, while the Philips tube output is only one-half inch. This difference in size of the outputs of the tube required a decisisn on how to compare them. It seemed desirable to have the final film-track images of the two systems the same size. This could be achieved in two ways: use the same lens system for both tubes, then enlarge the Philips film-track images by a factor of two to compare with the Westinghouse data. The other way was to use two different lens systems, selecting the lenses so that the final images were the same size. The latter alternative was selected so that any limitations associated with enlarging and reproducing the film would not have to be reckoned with. It was felt that working with the film from both systems through only one stage of photographic development was better than having an additional photographic process for one of the systems.

The camera originally used was a 35-mm Bell and Howell "Eyemo." Later a 35-mm Arriflex camera was substituted, primarily because of the desirability of the through-the-lens monitoring system of the Arriflex. Both of these cameras operate from non-synchronous motors, and their speeds vary some during a test. This is one factor which limits the accuracy of these determinations. Because of the major modification required to substitute a synchronous motor for the standard camera drive motor, no attempt was made to do so. If a system such as this is to be used for routine clinical examinations, it is strongly recommended that the camera be modified to be driven by a synchronous motor and that the X-ray pulses be synchronized with this drive in the same manner as was done with the conventional system. This is necessary to reduce the radiation to the patient to the lowest possible value. The limited clinical use of the system in this program did not justify the modification of the camera.

Both image tubes have provisions for mounting near the output end of the tube. A special aluminum ring was attached to each tube to provide a mounting fixture which allowed the tubes to be interchanged on the fixed support. The Westinghouse tube is longer than the Philips tube so a system of standoffs was required to place its input phosphor at the same distance from the X-ray-tube target as the phosphor of the Philips tube. The high voltage cables for each tube are clamped to the fixed tower, allowance being made for the up-and-down motion of the tube. Due to the difference in weight of the two tubes, it was necessary to put a lead ballast on the aluminum attachment ring of the Philips tube so that when the tubes were interchanged, no rebalancing on the tower mechanism was necessary. The camera mount attaches to either of the two attachment rings. When used with the Westinghouse tube, an additional lens retaining fixture is required.

1. Philips-Tube System

This system is shown diagrammatically in Figure 8 and photographically in Figure 9. The coupling lens is an f/1.5, 55-mm Schneider-Kreuznach lens and the camera lens is an f/1.8, 75-mm Astro-Gesellschaft lens. This tube is supplied complete with a high voltage power supply which supplies 25 KV to the tube. This supply requires a 220-volt single-phase ac source.

The original Philips tube supplied for this work had a central bright spot on the output phosphor. This spot became worse as the tube was used. Correspondence with the manufacturer, over a period of several months, disclosed that the central bright spot was caused by positive ions in the tube which were being focused by the electrical lens on the input phosphor where

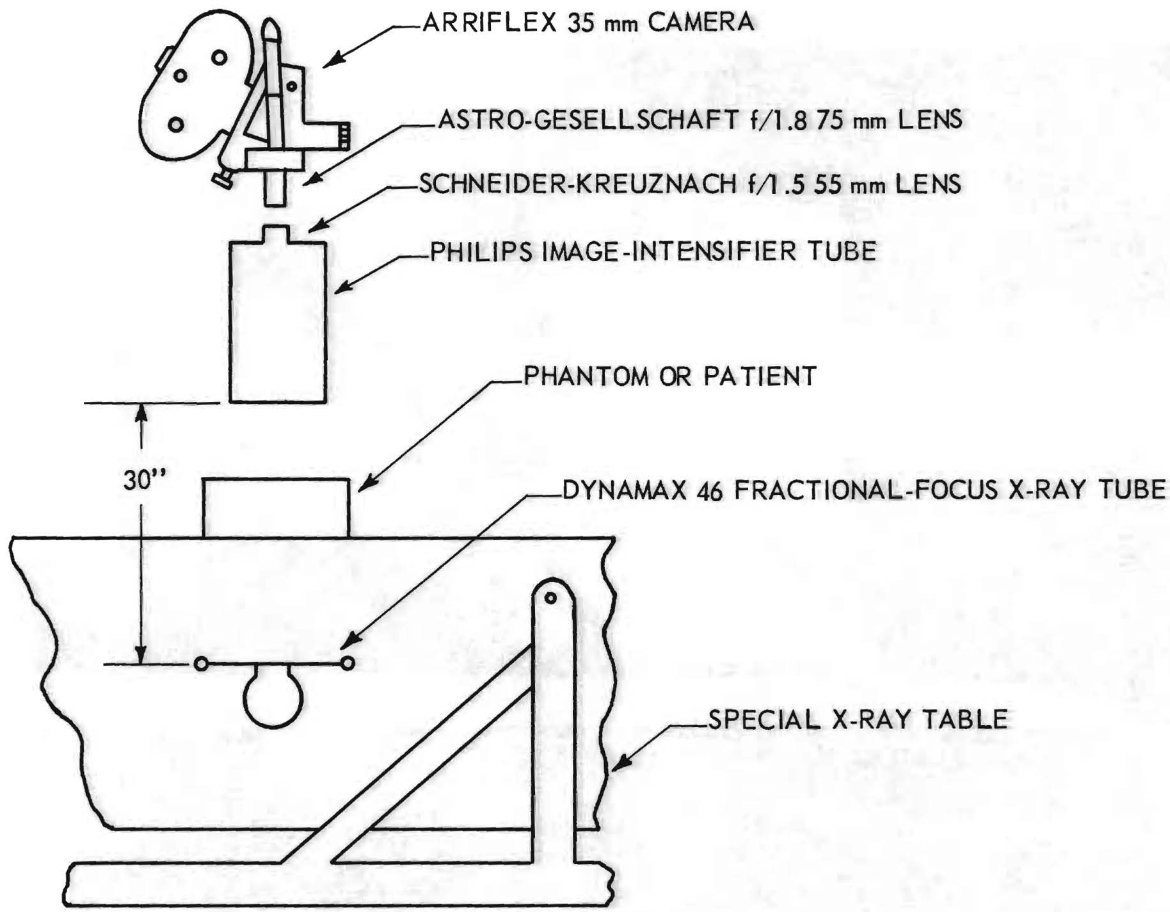


Figure 8. Functional Diagram of the Philips Image-Intensifier Tube System.

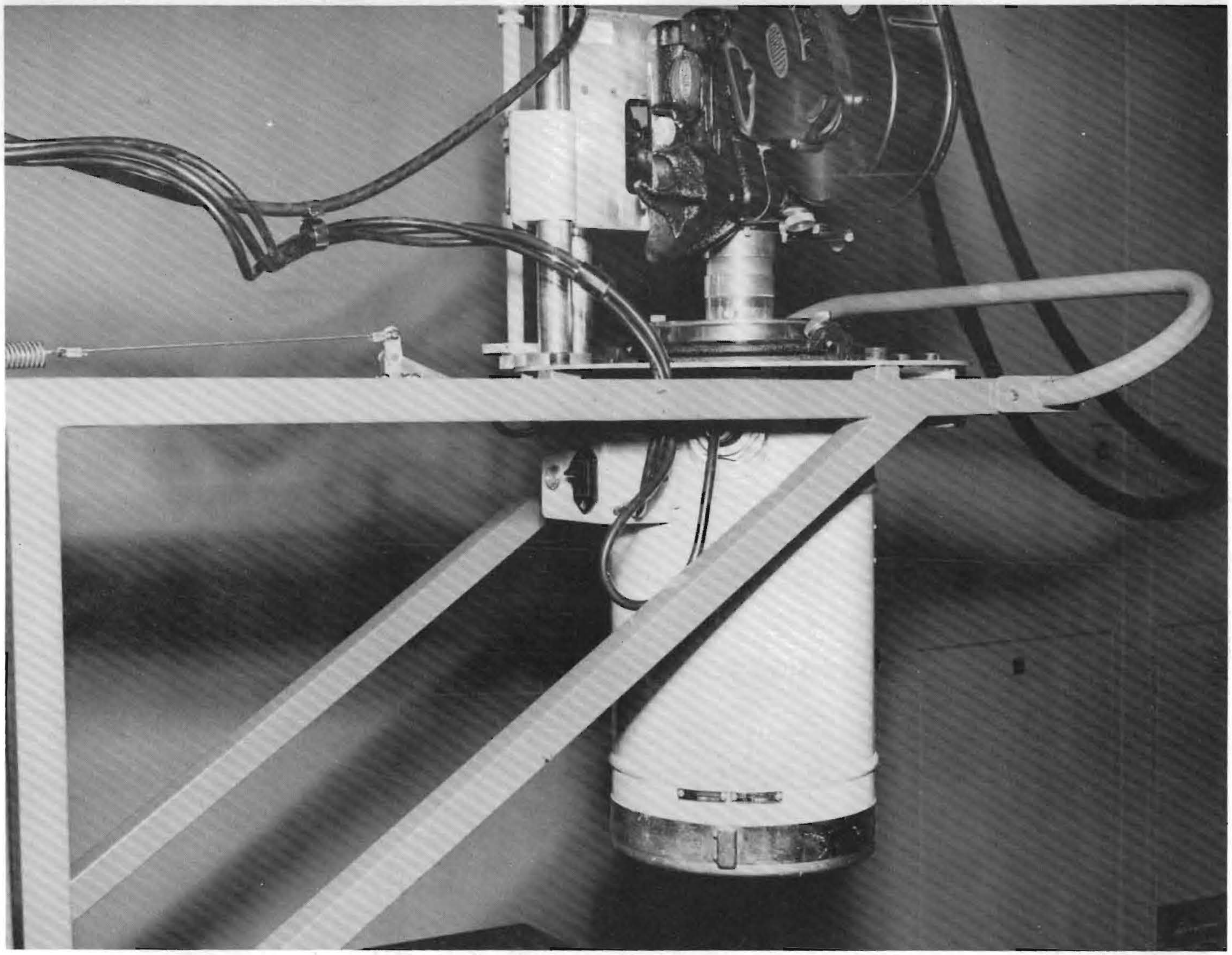


Figure 9. Philips Image-Intensifier Tube System.

they were causing secondary electron emission which, in turn, was focused on the output phosphor by the lens. The source of these ions was not disclosed, but it has been suggested by others that the use of an organic binder on the screen may make the outgassing marginal. A replacement tube was obtained and the tests reported here were conducted with this second tube. This tube has been operated for several months and appears to be free of the defect in the original tube. Both tubes, except for the central bright spot in the first, seem to be free of anomalies.

2. Westinghouse-Tube System

Figures 10 and 11 refer to this system. The f/1.8, 75-mm Astro-Gesellschaft lens is used for a coupling lens on this system. The camera lens is an f/2.0, 50-mm Apochromat Kinoptik Paris lens. A 30-KV power supply was furnished with the tube and the system was installed by the local Westinghouse service representative as a service that goes with the tube. This power supply operates from the 110-volt ac line.

The first tube received had an intensity gradient across the output screen such that the tube could not be used for the proposed evaluation tests. Correspondence with the manufacturer showed that the test film taken by them prior to the issue of the tube indicated just such an irregularity. At that time such irregularities were within the manufacturing tolerances. Since then, however, the acceptance standards have been raised and some thought has been given to the possibility of issuing a premium line of image tubes which have been specially selected for cinéradiography. A second, and in this case, a hand-picked tube was supplied by the manufacturer. This tube was used in the evaluation program. Use of a hand-picked tube in a comparison program is a questionable procedure, although it is believed that anyone else interested in ciné work would be able to obtain an equivalent tube but might have to pay a premium price.

C. Experimental Procedures

1. Film-Processing Technique

Several different types of film have been used in this work, but the film which was selected for the system comparisons was Eastman Kodak

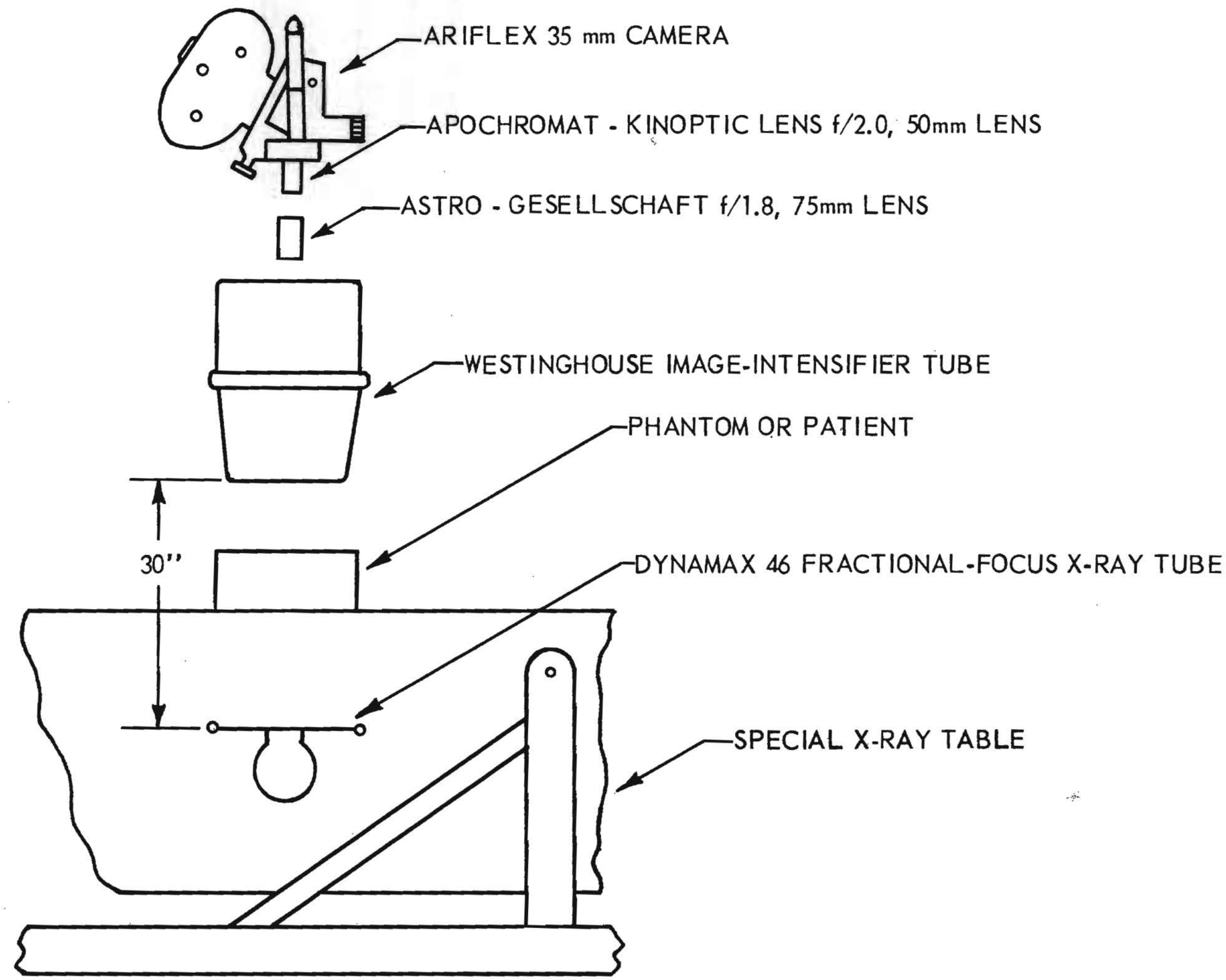


Figure 10. Functional Diagram of the Westinghouse Image-Intensifier Tube System.

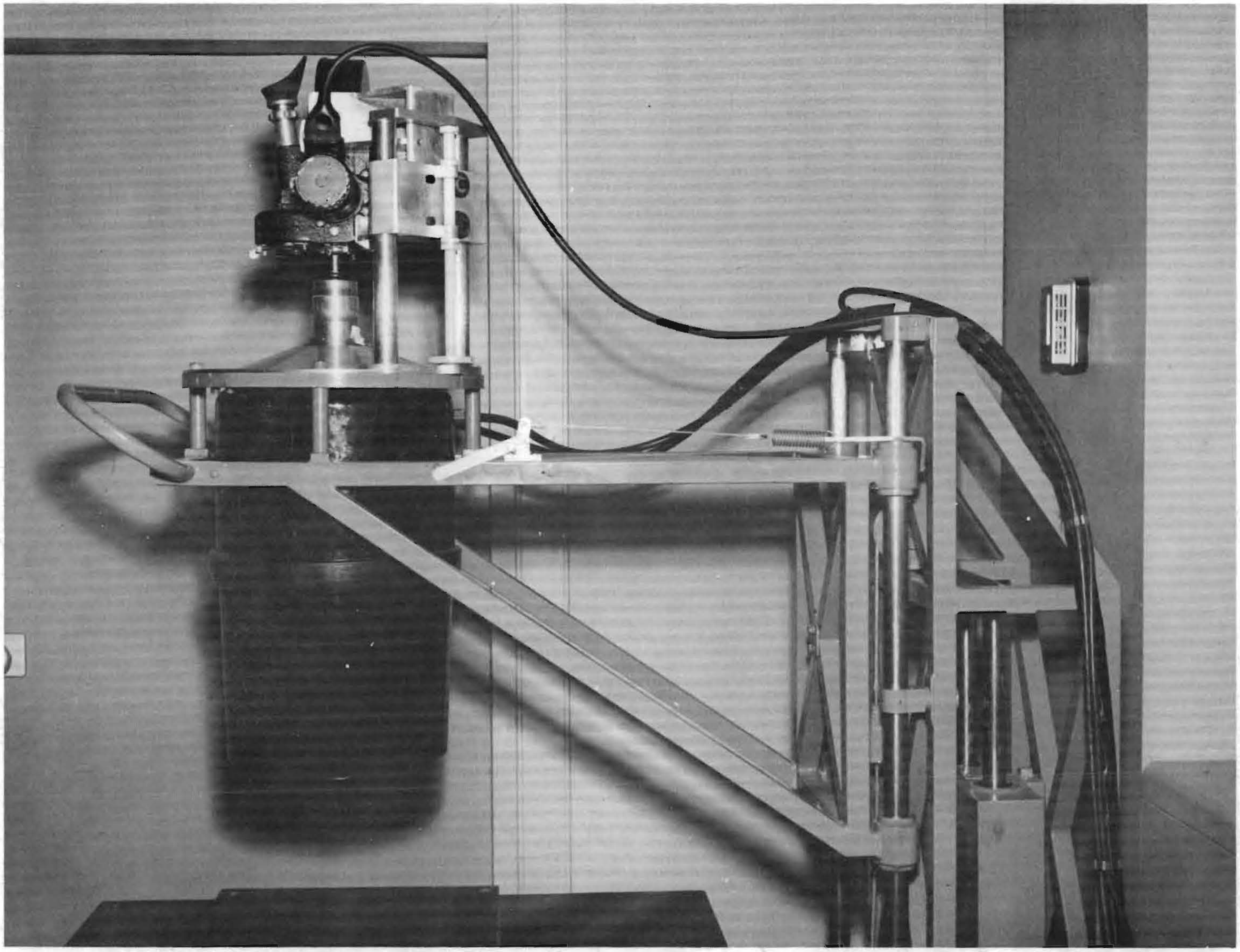


Figure 11. Westinghouse Image-Intensifier Tube System.

Special Linagraph Ortho, Emulsion No. S. O. 1130. This film was the "fastest" film tested and as discussed later its grain size was not large enough to limit resolution. (Here "resolution" is used in the optical sense.)

Several different film-processing techniques were tried. The best results were obtained using Kodak Liquid X-ray Developer. The particular properties desired are high contrast and maximum film sensitivity. Film development was carried just short of fogging the film. Periodic tests indicated that in all cases the gamma of the film was at least 1.8. By developing in Kodak Liquid X-ray Developer at 68 degrees F. for six to seven minutes the maximum contrast and detail were extracted from the film.

A standard refrigerated X-ray sheet-film developing tank was used with modified 14 x 17-inch film holders available from the Eastman Kodak Company. These holders have guide spools for winding 35-mm film about the frame and will hold about twenty feet of 35-mm film.

Constant-density and resolution (Radiologist's sense) studies were made with the original negatives. However, for the clinical phase of the work it was desirable to have positive 16-mm prints for projection. The Public Health Service Communicable Disease Center at Chamblee, Georgia, has the equipment for this type of work, and the project is indebted to Mr. Tully Clark of that organization for his cooperation in this phase of the program.

2. Constant-Density Curves

To obtain the constant-density curves for each system with the minimum amount of data taking, the following procedure was used. The test-object thickness was varied from about 4 cm to 18 cm in steps of 2 cm. An estimate was made of the MAS and KV values necessary to obtain a film density of one* for a given test-object thickness, then three exposures were made, all having the same KV, but with variations in MA so that the MAS values bracketed the estimated point; that is, one point was high, one was low, and one was at the

- - - - -

* Density, as used herein, means the observed density less the "inherent background" of the film. This is the density which is approximately proportional to the radiographic exposure. A density of one was selected as the density which most radiologists prefer for diagnostic film.

estimated value. The optical density of the film for each exposure was determined for at least five frames, then these five values were averaged and the inherent background of the film subtracted. This gave three average densities showing the relationship between MAS and density, D, for constant KV and test-object thickness, t. A smooth curve connecting these points will cross the line $D_c = 1.00$* if the original estimate of MAS and KV was a good one. The value of MAS which would expose the film to a density of 1.00 is the intersection of this curve and the line $D_c = 1.00$.

The next and final step was to plot the MAS for a density of 1.00 versus the test-object thickness, a curve being obtained for each value of KV. These are the technique curves given in Figures 15, 16 and 17. The graphical procedures discussed above are illustrated in the sketches of Figure 13.

In order to smooth out small variations due to developing procedures, an aluminum stepwedge was used as a standard to determine a corrected density, D_c.** The procedure was as follows: the stepwedge was radiographed at a standard X-ray technique on each piece of test film which was to be developed.*** The maximum length of film which could be processed at one time was about 20

- - - - -

* If the curve does not intersect the $D_c = 1.00$ line, the curve may be extrapolated to this line and a more accurate estimate of the MAS for a density of 1.00 can be made and another set of three points obtained. D_c is defined later.

** Because of the difference in size of the input screens of the image-amplifier tube systems and the conventional system, it was necessary to use two penetrameters, or "stepwedges." The penetrameter used with the conventional system had six steps ranging from 3/16 to one and 1/8 inches, in steps of 3/16 inch. The one used with the image-amplifier tube systems consisted of 9 one-inch diameter holes in a one-inch-thick piece of aluminum. These holes varied in depth from 0.10 inch to 0.90 inch in steps of 0.10 inch. This effectively gives a "stepwedge" with ten steps. These penetrameters are shown in Figure 12.

*** For the stepwedge used with the conventional system, this technique was 100 KVP and 100 MA or 1.67 MAS per film frame. For the stepwedge used with image-amplifier tube systems, the technique was 70 KVP and 20 MA or 0.417 MAS per film frame for the Westinghouse tube system and 70 KVP and 10 MA or 0.208 MAS for the Philips tube system.

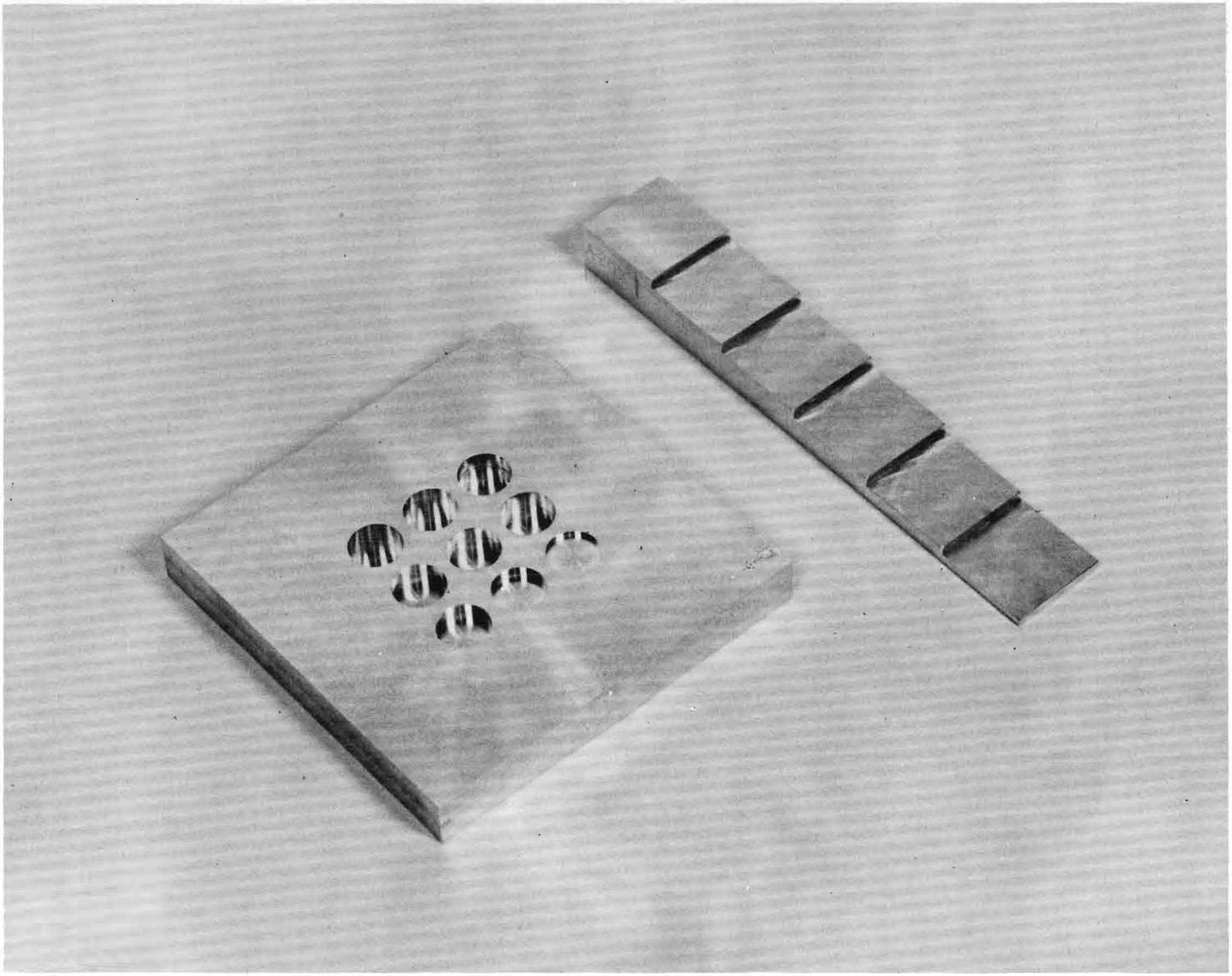


Figure 12. Aluminum Penatrameters Used to Standardize Film-Processing Technique.

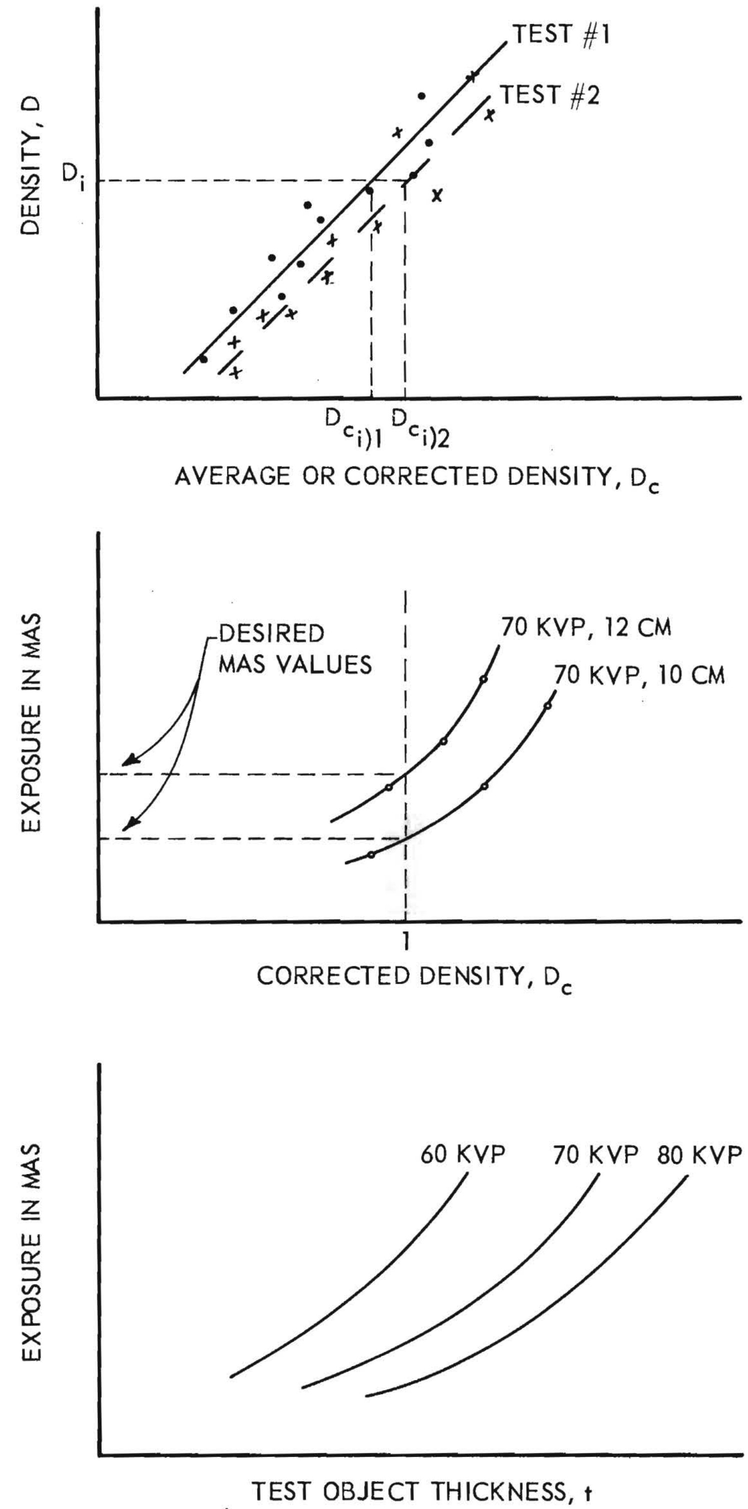


Figure 13. Illustration of Graphical Procedure Used in Obtaining Constant-Density Diagrams.

feet. This meant that two sets of three exposures (to determine two points on the constant-density curve) and the exposure of the stepwedge could be made on one piece of film. The data for the constant-density curves on each one of the systems consisted of 30 to 40 points, requiring between 15 to 20 separate developing processes. This meant that 15 or 20 different stepwedge exposures were made. The value of density for each step of each stepwedge exposure was determined by averaging five frames of that exposure. Then an average density, D_c, was obtained for each step by averaging the averages for each exposure. By plotting the density values for each step of a particular exposure versus this average for all the exposures of that step, a curve was obtained which related the density for any one exposure to a corrected density. Then this curve was used to correct the densities of the data-point exposures. These corrected densities, D_c, were actually used in the calculations and procedures indicated above.

3. Resolution Studies with the Special Test-Object

Ten sizes of polyethylene tubing were used. These sizes are given in Table I below. The tubing was arranged in order of increasing size on the

TABLE I

DIAMETERS OF TUBING IN VEIN PHANTOM

Tube Number	Inside Diameter (mm)	Outside Diameter (mm)
1	0.28	0.61
2	0.38	1.09
3	0.58	0.965
4	0.76	1.22
5	0.86	1.27
6	1.14	1.57
7	1.40	1.90
8	1.57	2.08
9	1.67	2.42
10	1.77	2.80

moveable plate in the tank. Radiographs were made with the conventional system and the two image-intensifier tube systems for the plate at the top, middle and bottom of the filled portion of the tank for the tank filled to depths of 10, 15 and 20 cm. The tubing was filled with either 17.5, 35, 50 or 75 percent aqueous Diodrast solutions.

In addition, experiments were conducted with the Lumicon*, the Westinghouse Fluorex system**, the General Electric TV-X system***, and with the conventional fluoroscopy.

4. Determination of Radiation Hazard to Patients and Operating Personnel

The air-skin dose to the patient was determined at the table top using a Model 70 Victoreen Condenser r-Meter, with a 25-r chamber. The determination of the radiation hazard to an operator standing beside the table was made using a Victoreen Minometer, with a 10-mr chamber. The patient was simulated by a torso-shaped bag of rice. The experimental set-ups are shown in Figures 2 and 14.

D. Results

1. Constant-Density Curves

The curves described here have several useful purposes. First, in order to conduct an examination on a patient, some idea of the radiographic technique for the examination must be had. Technique, as defined previously, refers to the combination of X-ray KVP and MAS required to give the desired

- - - - -

* The Lumicon system is a closed-loop television system manufactured by the Friez Instrument Division of the Bendix Aviation Company. The system consists of a fluorescent screen and focused grid, an f/0.79 Fluoro-Ectar lens, an image-orthicon television tube and the related circuitry, and a monitoring video repeater. The system used for these tests was made available by the Signal Corps at Fort Monmouth.

** The Westinghouse Fluorex system is a Westinghouse image-intensifier tube with a special optical system for direct viewing of the fluorescent screen by the radiologist. This system is located in the X-ray Department at the Emory University Hospital.

*** The General Electric system is an experimental system utilizing a large area photoconductive X-ray pickup tube developed by that company. The output of this system is presented on a monitoring video repeater in a manner similar to the Lumicon. This system has been made available to Emory University by the General Electric Company.

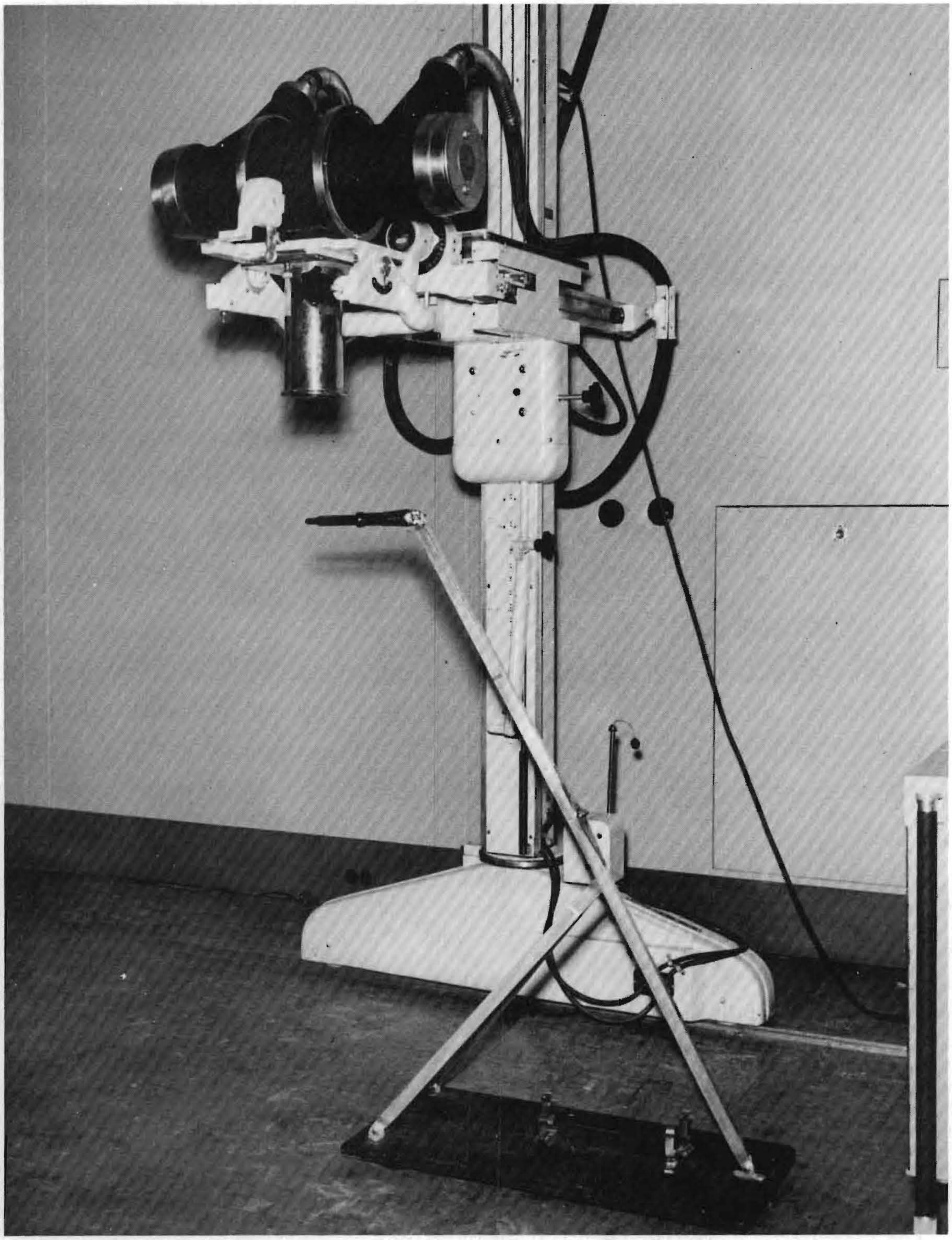


Figure 14. View of Setup for Determining Air-Skin Dose to Patient.

darkening of the film for a particular test object or portion of the anatomy. Second, these curves are indicative of the relative merits of a system. That is, if constant-density curves for two systems are compared, the system which requires the least radiation to a patient for a particular examination is the best, assuming all other factors equal. To illustrate, if for the same KVP system A requires 3 MAS for a particular examination, while system B requires only 1 MAS, then system B is the preferred system because the patient would receive only about 1/3 the radiation required for an examination with system A.

The constant-density curves for the three systems which have been studied are given in Figures 15, 16 and 17. These curves refer to the particular systems, including the optical, which have been described in this report, and to the particular photographic film, Eastman S. O. 1130, as previously mentioned. These curves are primarily useful in determining the proper technique for use in an examination with one of the systems. However, as discussed in a later section they may be used to determine the "amplification factors" of the image-amplifier tube systems as compared to the conventional system.

These curves have been determined for a Masonite Prestwood test-object. This material is similar in absorption to tissue and adequately simulates the lower portions of the anatomy. For the less dense upper anatomical regions, a correction factor of 10 to 20 percent must be used in applying these curves. However, as previously mentioned, an error of this magnitude is not sufficient to make the film unuseable.

2. Resolution Studies

As mentioned previously the determination of resolution in terms of dense objects, such as metal strips, for X-rays, or in terms of parallel black and white lines in conventional photography is really meaningless in clinical radiography.* Here the interest is in the ability to differentiate between tissue and bone or between different kinds of tissue.

- - - - -

* A more academic approach has been made by some groups. See, for example, Coltman, J. W., "The Specification of Imaging Properties in Response to a Sine-wave Input." Journal of the Optical Society of America 44, 6, 468-71 (1954).

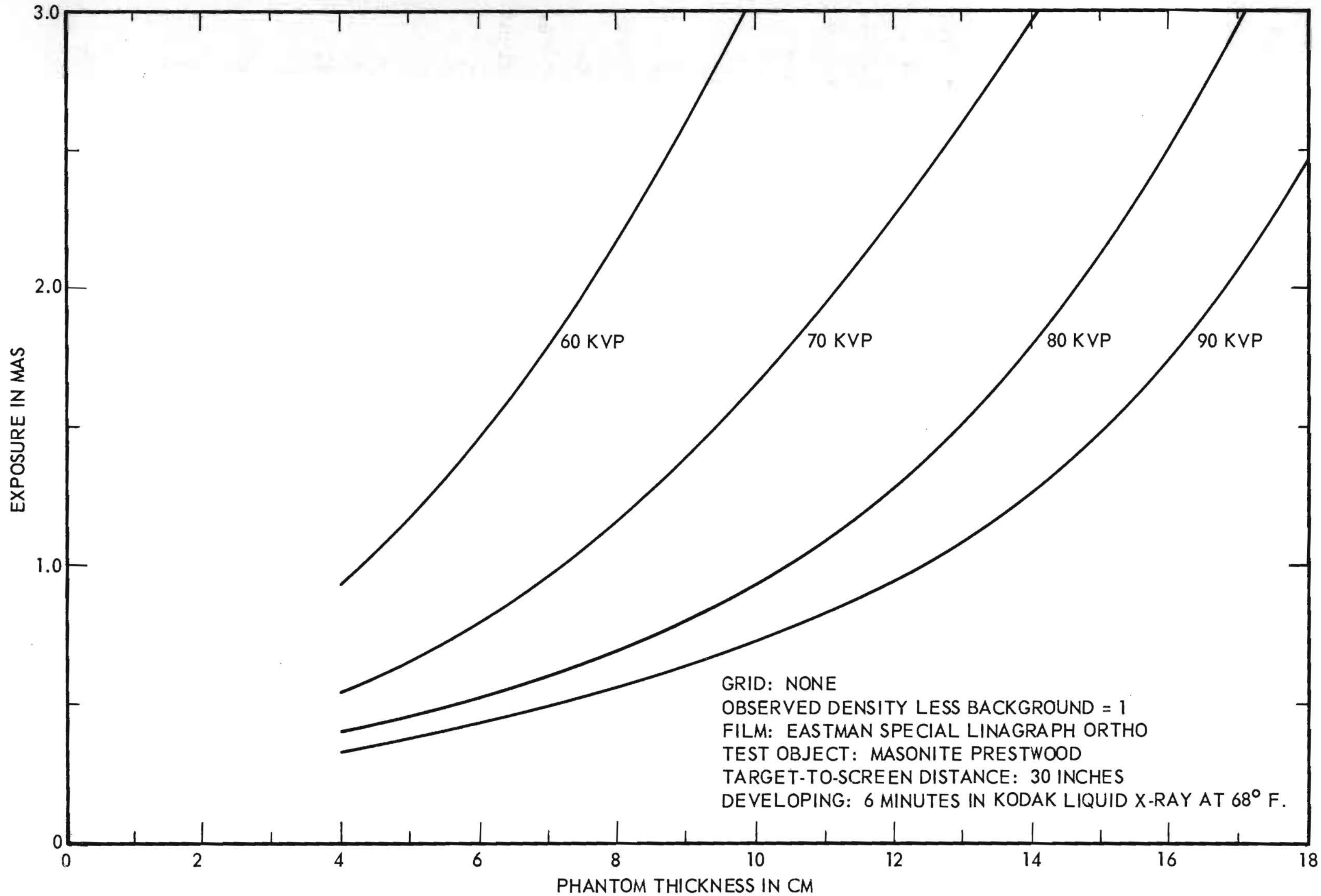


Figure 15. Constant-Density Curves for the Conventional Cinéfluorography System.

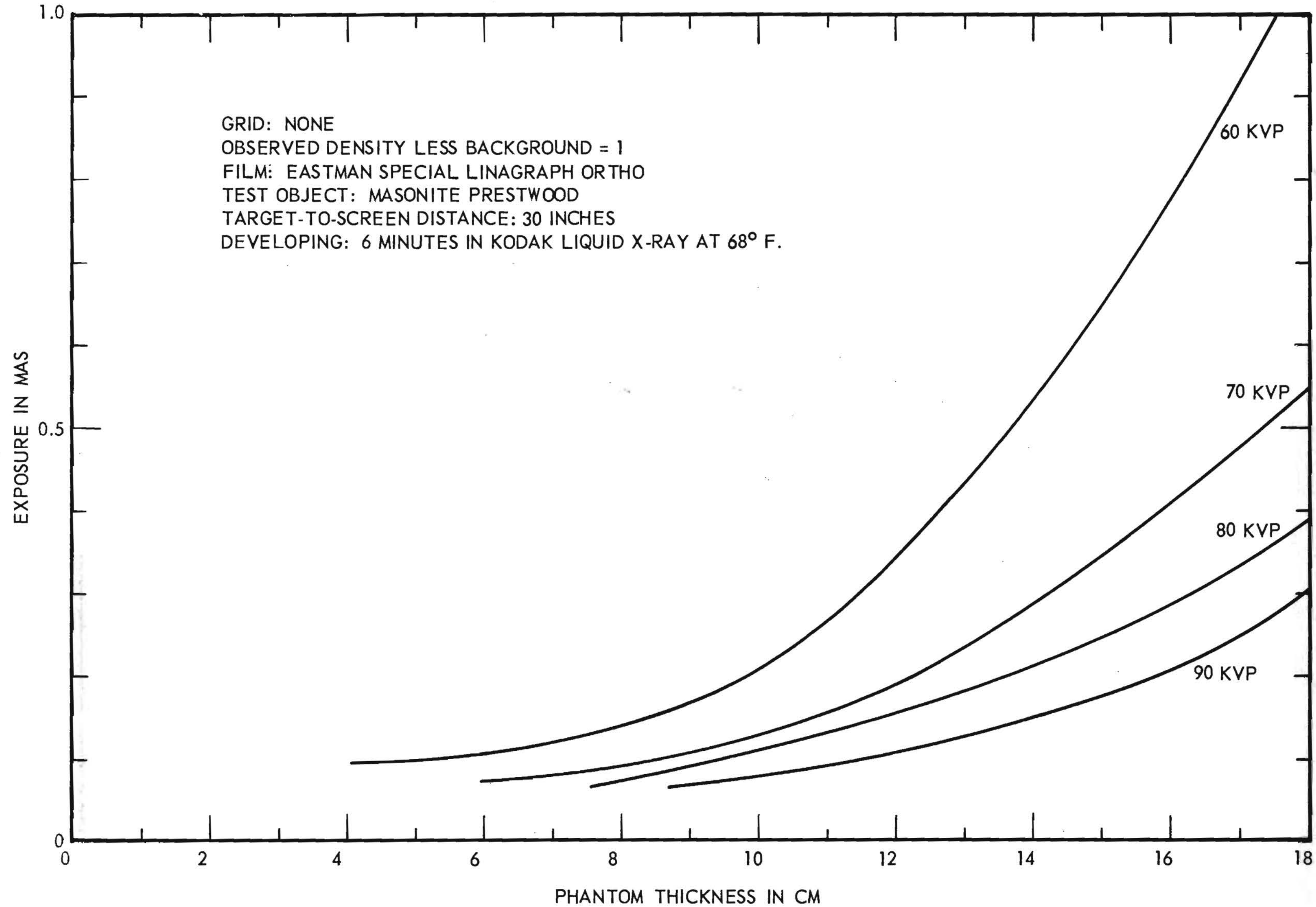


Figure 16. Constant-Density Curves for the Philips Image-Intensifier Tube System.

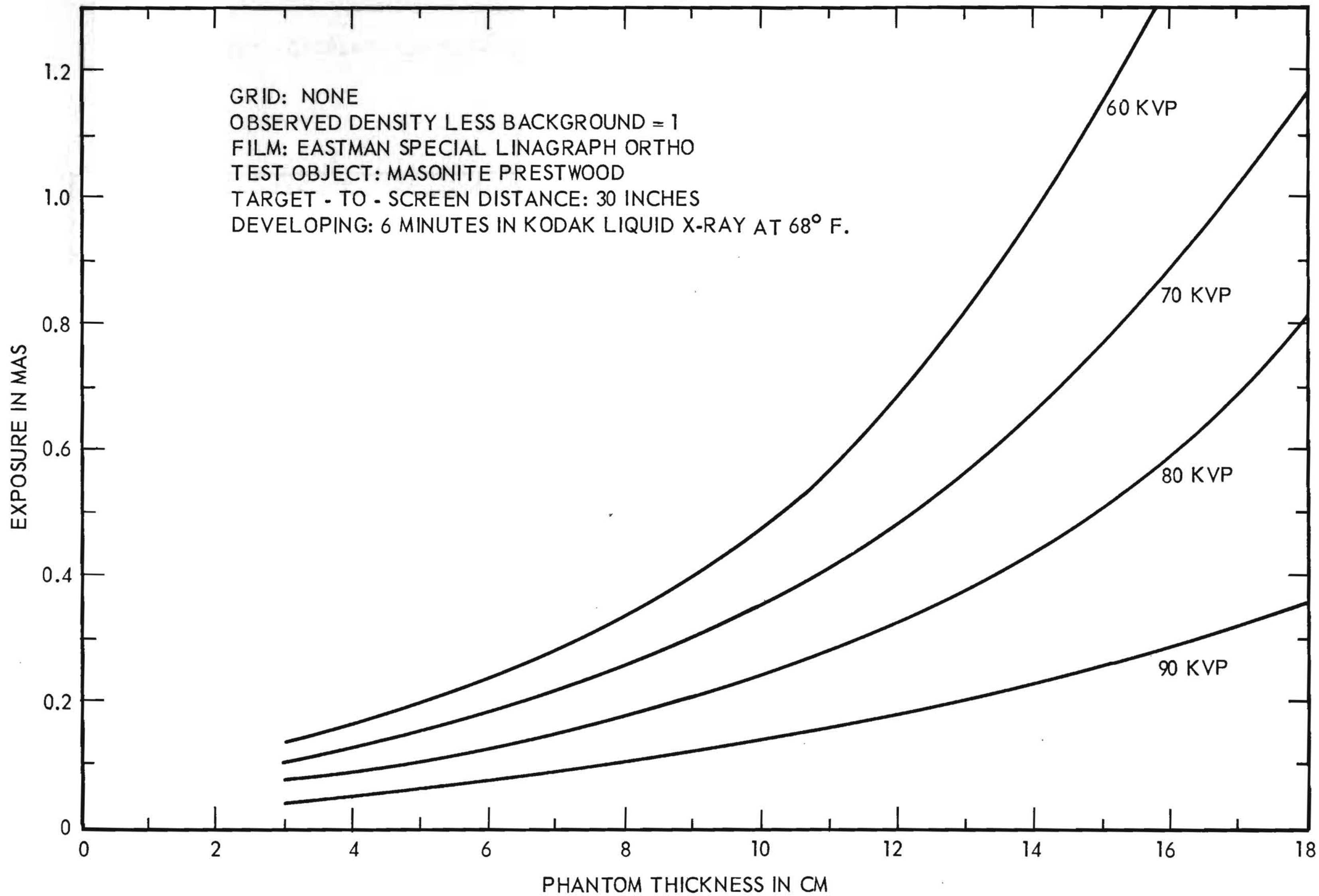


Figure 17. Constant-Density Curves for the Westinghouse Image-Intensifier Tube System.

Of particular interest in the study of the functions of the organs of the body is the ability to see small arteries or veins. Image-intensifier tubes, because of their limited field of view, less than five inches for the presently available tubes, have been particularly useful in the study of the smaller organs of the body. The field in which they have perhaps been the most useful is infant angiocardiography.

A special test-object or "vein-phantom" was constructed, as discussed earlier, to determine the minimum vein size which a given system could resolve. The normal clinical procedure in studying a particular organ is to fill the organ with a radio-opaque medium. As even the best radio-opaque medium or "contrast media" causes some danger or discomfort to the patient, it is desirable to use as low a concentration of contrast media as possible. The tests reported here considered the concentration of the media as well as the diameter of the vein.

Some objection to this procedure has been noted in the literature.* The assertion is made that tubing such as used here may be seen without a contrast-media filling. Tests have shown that when the tubing is filled with water and submerged in the tank, it cannot be seen by experienced radiologists either with the ciné systems or with conventional radiography employing calcium-tungstate screen casettes.

Although tests were made for the tubes at various depths in the box, and for the box filled to levels of 10, 15 and 20 cm, significant variations of the minimum resolvable tube diameter with these different settings were not observed. Diodrast, a commercially-available contrast media was used. Concentrations less than about 25 percent are not considered diagnostic. As most actual injections will be diluted by a factor of two or three upon entering the vein, this means that the injection percentage must be 50 to 75 percent. The values in Table II are for a Diodrast concentration of 35 percent, a focus-to-screen distance of 30 inches, and an optimum technique for each

- - - - -

* Mattsson, Ove, "Practical Photographic Problems in Radiography." Acta Radiologica Supplementum 120, Stockholm (1955).

TABLE II

COMPARISON OF RESOLUTIONS OF RADIOGRAPHIC SYSTEMS

System	Minimum Resolvable Tube Diameter (mm)
Conventional Ciné	1.67
Philips Image Amplifier and Ciné Camera	0.58
Westinghouse Image Amplifier and Ciné Camera	0.76
Conventional Fluoroscopy*	greater than 1.77
Westinghouse Fluorex (with Accommodation)*	0.58
Westinghouse Fluorex (without Accommodation)*	0.76
Bendix-Friez Lumicon*	0.86
General Electric TV-X*	0.58**

* The values given were obtained in the conventional manner for these systems, that is, by direct observation of the output images.

** This value is for the tubes at the bottom of 10 cm of water. The X-ray tube supplied with this system is a fractional-focus stationary anod type with a maximum current of 10 MA. This did not produce sufficient intensity to give an image with 20 cm of water.

system. The tubing support-plate was suspended at 10 cm in 20 cm of water. The largest tubing available had a diameter of 1.77 mm. This tubing could not be resolved by the conventional fluoroscopy system.

The Fluorex system is a Westinghouse image-amplifier tube with a special optical system made by Westinghouse for direct observation by a radiologist. Accommodation means dark adaptation of the eyes. This requires that an individual stay in a dark room for 15 to 30 minutes or wear radiologists' red goggles for an equivalent time before looking at the image.

Both Kodak Plus-X and Eastman S. O. 1130 film types were used in these tests. Best results were obtained with the more grainy, but higher contrast, type S. O. 1130.

3. Radiation Hazard

One of the primary functions of any image-intensifying system is to reduce the amount of ionizing radiation which is received by the patient and operating personnel. The relative comparison of exposure between two systems is the ratio of the X-ray tube currents for the two systems, with KVP constant and for the same photographic effect, that is, film darkening. For a given X-ray tube and tube potential, the roentgen output is proportional to the tube current and exposure time. That is, $R \propto MAS$, where R is the roentgen output.

The relation between roentgen output and tube potential is more complex because absorption and ionization are energy dependent. Hence, in the following discussion, the roentgen output will generally be stated in terms of the roentgen rate, $(r/100\ MAS)_{KVP}$, which is different for each tube potential.

Any material in the X-ray beam acts as a filter for components of the radiation. For the conventional system filtration is present in the X-ray-tube window, added aluminum filters and in some absorption due to air between the X-ray source and the patient. The effect of air filtration is small for the medium-energy range where these data are taken. This is especially true where additional filtration is present. The aluminum filters strongly absorb the soft radiation which would be effected by the air.

In the image-intensifier systems, the total filtration was the same for both image tubes. These systems have filtration properties similar to the conventional system, except that here an under-table tube was used. This interposes the table top between the patient and the X-ray source. This serves as both a filter and introduces an additional source of soft radiation. This additional radiation is composed of secondary and multiply scattered X-rays and photoelectrons.

The total filtration between the X-ray source and the patient and between the X-ray source and the screen are given in Table III for both the conventional system and for the image-intensifier systems as used in the tests reported here.

The radiation to patient and operating personnel is further reduced by the use of cones for limiting the divergence of the primary beam. For the two systems, cones are used to limit the beam to the field size of the input fluorescent screens. This reduces the total-body dose to the patient by

TABLE III

ALUMINUM EQUIVALENTS OF FILTRATION

Item	Systems: Image-Intensifier	Systems: Conventional
X-ray-tube window (Pyrex glass)	0.5 mm	0.5 mm
Added filters (Aluminum)	2.9 mm	2.5 mm
Table top (Phenol-formaldehyde lamination)	1.7 mm	
Total between source and skin	5.1 mm	3.0 mm
Table top (Acrylic resin)		0.8 mm
Screen backing plate (Phenol-formaldehyde lamination)		0.7 mm
Total between source and screen	5.1 mm	4.5 mm

reducing the volume irradiated by the primary beam. It also reduces the amount of scattered radiation received by both the patient and the operator because it reduces the scattering volume in the patient.

Figure 18 is a plot of the roentgen rate, $(r/100\ MAS)_{KVP}$, versus KVP for the two X-ray systems. The rate for the conventional system, which uses the Super Dynamax tube, is given for three focus-to-skin distances, abbreviated fsd, while that for the image-intensifier system, which uses the Dynamax 46 tube, is given only for an 18-inch fsd. The curves in Figure 18 are for a continuously operated X-ray source. The r-output for the image-intensifier X-ray-source, curve 3, is slightly greater than the equivalent output of the conventional X-ray-source, curve 2. This is due to the scatter in the table top for the under-table tube. As discussed previously, the actual exposure to the patient is reduced by synchronizing the X-ray source with the camera drive in the conventional system and could be reduced similarly with the image-amplifier systems. This effectively reduces the radiation to the patient to one-fourth the values shown on the curve in Figure 18. Because of the major modification required to synchronize the Eyemo or Arriflex cameras, this was

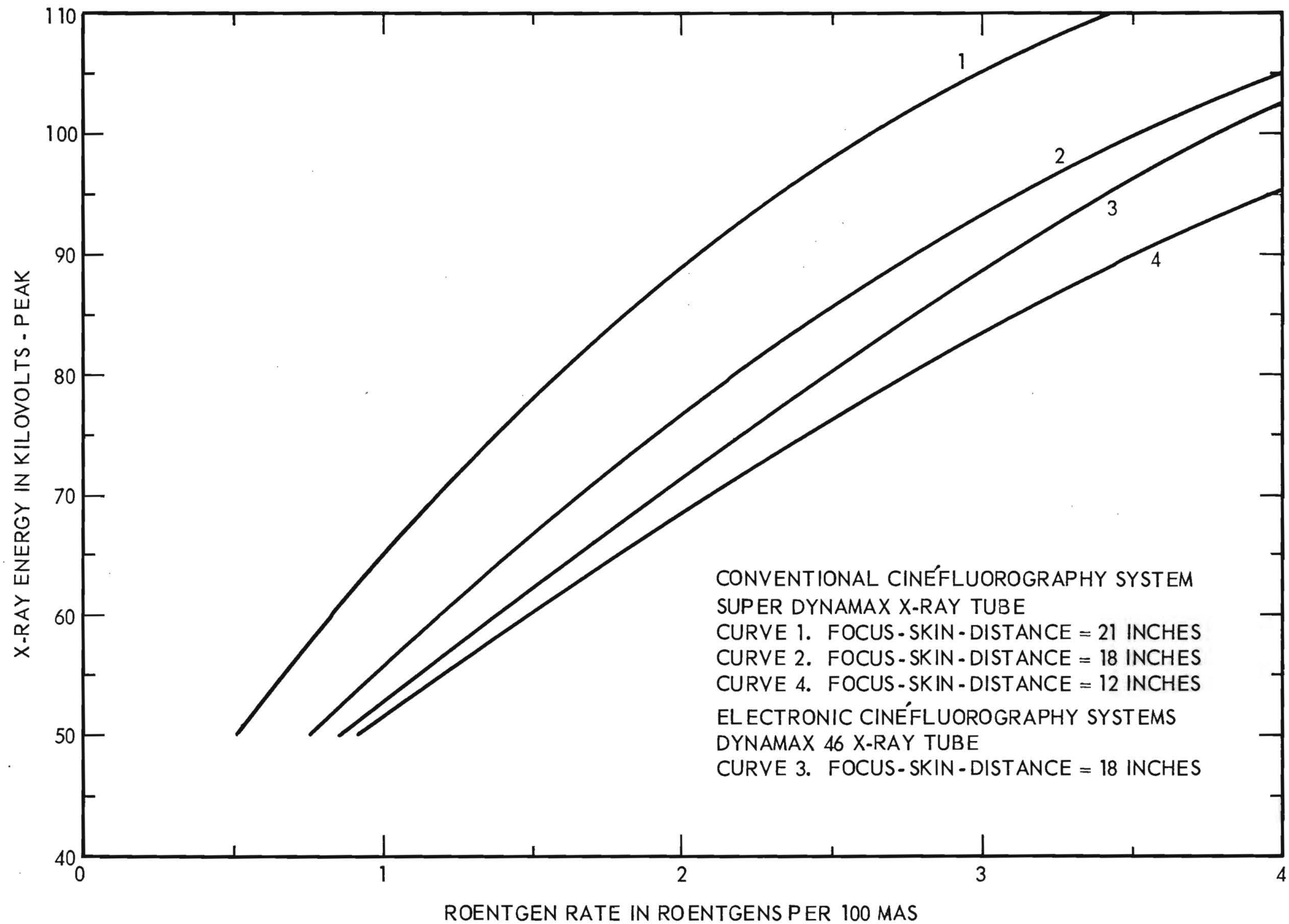


Figure 18. Roentgen Outputs for Cinéfluorography Systems.

not done with the image-amplifier systems. Figure 19 compares the radiation to a patient for the same typical examination with each of the three systems assuming the image-intensifier-system camera to be modified to operate synchronously.

In normal clinical procedures there is usually no need for operating personnel to be exposed. There are exceptions, of course, such as the necessity of being near the radiation source and patient during cardiac catherization and injection of radiopaque contrast media. Also, visual monitoring requires that the observer be near the radiation source. The proper use of protective clothing makes most procedures quite safe, however. With the conventional system a greater hazard is present because of the higher X-ray-tube currents and the larger field-size of the X-ray beam. For example, the largest probable dose which would be received by personnel standing beside the patient during a normal six-second cinéfluorographic examination would be about 0.1 r for the conventional system and 0.005 r for the image-intensifying systems. This difference is due to two factors: (1) the "amplification factor" of the image-intensifier tube and (2) the fact that the volume of the patient irradiated by the beam is much smaller for the image-tube system than for the conventional system. The second factor causes the above figures to be misleading.

One last variation that might be employed in radiographic practice is the use of a grid consisting of thin strips of lead mounted parallel to the X-ray beams in a radiotranslucent base to filter out the secondary and scattered radiation between the patient and the fluorescent screen. This procedure gives a better-defined image and hence better perception of detail. However, the use of a grid requires a net increase of exposure to the patient of about 40 percent.

E. Discussion of Results

1. Comparison of the Optical Efficiencies of the Three Systems

The three systems have been shown both photographically, Figures 2, 9 and 11, and schematically, Figures 1, 8 and 10. The projection (or coupling) lens furnished with the Philips tube is a 55-mm, f/1.5 lens. Using a 75-mm, f/1.8 lens in the camera with this system gives an image 19.1 mm in diameter

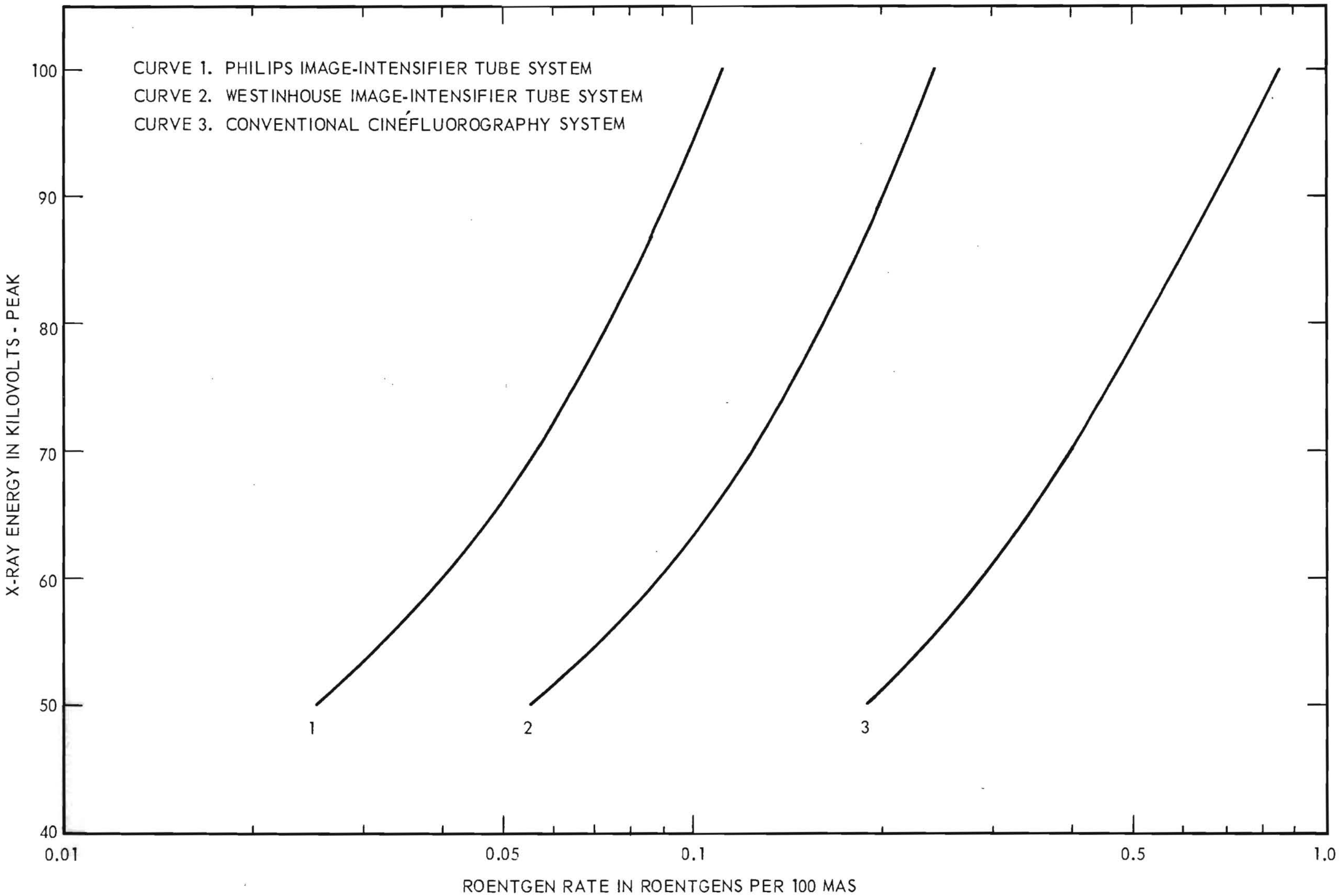


Figure 19. Estimated Ideal Roentgen Rates for Similar Examinations With Different Systems (Assumes Synchronous Operation of All Systems).

on the film. For the Westinghouse tube a coupling lens of 75-mm, f/1.8 and a camera lens of 50-mm, f/2.0 gives an image on the film 19.0 mm in diameter. The choice of lenses was controlled by three factors: (1) the desire to have the film images from the two image systems approximately the same size, (2) the desire to record the most information on the film, and (3) the desire to have the most efficient optical systems available. The first of these factors is discussed above. The second suggested over-filling the shorter dimension of the 35-mm film frame in order to use more of the longer dimension. A standard 35-mm film frame is 16 mm by 22mm; the short dimension is overfilled 3 mm top and bottom, but 19 mm of the long dimension is used, giving an "information area" of 263 mm^2 rather than 201 mm^2 if the whole circle were contained in the usual frame. Referred back to the input screen, this gives an effective viewing area of about 4 inches diameter.

The third factor, the desire to have the most efficient optical systems available, was controlled by the necessity of using lenses which were available. After failing to find suitable lenses on the commercial market, the problem was taken to the optical group at the Signal Corps Engineering Laboratories. The lenses used in the systems represent the best lenses which they had available, and they are close to being the best which could be made for these systems.

While some gain could be had with more efficient optical components it is to be expected that the variation in output from one image-intensifier tube to another would be greater than this increase. Note that for the same relative optical magnification, the image intensifiers, especially the Philips, would appear even better.

2. Accuracy of Results

a. Constant-density curves. Periodic tests have indicated that the density values given on the constant-density curves can be duplicated $\pm$ 10 percent. The eye has difficulty distinguishing between a density of 0.9 and 1.1, except by contrast with adjoining areas. Variations in density discussed here are for the whole picture. Radiographs varying in average density within the ranges 0.9 to 1.1 can hardly be distinguished unless they are side by side.

b. Resolution. The limitations in the sizes of tubing available limit the accuracy of the resolution determinations to the extent that if one tube is resolved and the next smaller is not, all that can be said is that the resolution is less than the diameter of the smallest resolve tube and greater than the diameter of the largest unresolved tube.

F. Comparison of Experimental Data

One of the primary purposes of the experimental program of this contract was to determine the relative amplification of image-amplifier tube systems as compared to a conventional cinéfluorography system. The ratio of the radiographic effect for the nonelectronic or conventional system to the radiographic effect for the image-amplifier tube system which produces the same density negative for the same test object and X-ray-tube-target-to-fluorescent-screen distance was suggested as the amplification factor.* Several empirical equations have been written for the radiographic effect.** The most commonly accepted relationship is

$$\text{Radiographic effect} = \frac{C\ (MA)\ (S)\ (KVP)^n}{d^2}$$

where

C = a constant characteristic of the complete X-ray-to-developed-film system

MA = the X-ray tube current in milliamperes

KVP = the peak X-ray voltage in kilovolts

n = a number (approximately 5 for conventional radiography)

S = the X-ray exposure time in seconds

d = the distance from the X-ray source to the fluorescent screen or film

- - - - -

* Quarterly Progress Report No. 5, this contract.

** See, for example, Physical Foundations of Radiology by Glasser, Quimby, Taylor and Weatherwax. Published by Hoeber. Or Acta Radiologica 36-4, 311-332 (1951).

As discussed in Section V, an equation of this form does not hold in all cases considered. For this reason as well as for practical considerations, the apparent amplification factor, or simply the ratio of the MAS values for the same KVP and test-object thickness, will be used. An amplification factor defined thus is a function of KVP and is shown plotted versus KVP in Figure 20. The values presented here are for the systems as described in previous sections of this report. The optical magnification for each system is such that the maximum area of the 35-mm frame is used. If the same relative magnification was used for all three of the systems, the "amplification factors" would be much higher, especially that of the Philips tube system. The lenses used with these systems represent about the best optical components presently available; improvements in the optical efficiencies will not produce drastic improvements.

While an amplification factor based on the ratio of the radiographic effects, and one which is independent of the X-ray KVP is to be preferred, the determination of such a factor is dependent on determining a proper relationship between the radiographic effect and the X-ray parameters and such a universal relationship may not exist.

1. Philips Image-Amplifier Tube

The amplification factor for the Philips tube is given by curve 1 in Figure 20. It varies from a maximum of 13.3 to a minimum of 8.6, for various KVP. The average is approximately 11.

2. Westinghouse Image-Amplifier Tube

The amplification factor for the Westinghouse is represented by curve 2 in Figure 20. It varies from 6.1 to 4.1 as a function of KVP. The average is approximately 5.

3. Comparison of Philips and Westinghouse Image-Amplifier Tubes

The relative amplification of the Philips tube to the Westinghouse tube is shown as curve 3 in Figure 20. This factor varies much less as a function of KVP than the amplification factors of the image-intensifier tubes. The average value is approximately 2.

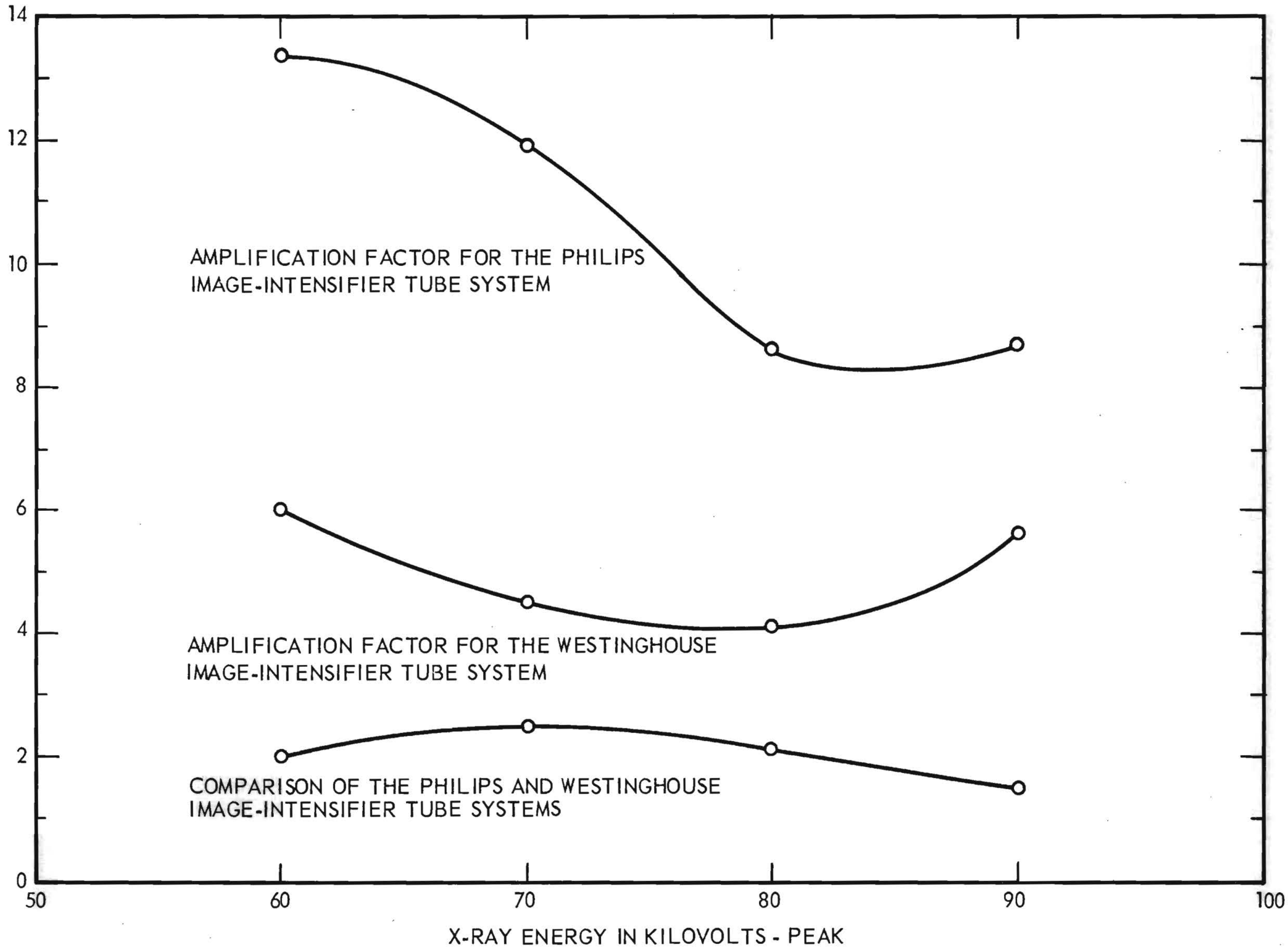


Figure 20. Comparison of Cinéfluorography Systems.

The fact that the comparison curve between the two amplifier systems is a more linear function of KVP than the comparison curves of the amplifier systems with the conventional systems would seem to indicate that the relationship of the factors effecting the radiographic effect is similar for the amplifier systems, but different for these systems and the conventional system. Further examination of these factors did not seem to be justified under this contract.

G. Clinical Studies

A total of 46 clinical investigations have been made. These may be categorized in several ways, as shown in Table IV.

TABLE IV

CLINICAL PROCEDURES

	Number of Investigations
Subject:	
Adults	26
Children	9
Dogs	11
System:	
Conventional Cinéfluorography System	29
Philips Image-Intensifier System	7
Westinghouse Image-Intensifier System	10
Area of Interest:	
Hearts and Chests	33
Abdomens	1
Extremities	3
Larynges	9
Use of Contrast Media:	13
Type of Film Used:	
Kodak Plus-X	10
Eastman S. O. 1130	35
DuPont Hi-Speed Pan	1

The image-intensifier systems were used in only 17 out of the 46 cases. The limited field of view with these systems causes a severe limitation in their usefulness. Many of the cases considered could not be studied with the intensifier systems for this reason.

V. THEORETICAL CONSIDERATIONS

The desirability of a concise mathematical expression relating the radiographic effect and the X-ray parameters has become more and more evident during the course of the work on this project.

According to Bierman and Boldingh*, and others, the product $(MAS)(KVP)^n$ should be constant for a constant blackening, or constant density, of a photographic plate if all other parameters, distances, test-object thickness, film-processing technique, etc., are held constant. The value of the exponent, n, given by these workers is between 4 and 6, with an average of 5, for both conventional radiography using intensifying screens and for miniature radiography, or cinéfluorography. The data reported here do not support this assertion.

Using data from the constant-density curves, Figures 15, 16 and 17, plots of ln(MAS) versus ln(KVP) for a given test-object thickness can be drawn. If the exponent n is indeed a constant, then such curves should be straight lines with a negative slope equal to n. For the conventional system and for the Philips tube system, n is approximately a constant. However, for the Westinghouse tube system, n varies over a wide range. The average values of n for the three systems were all in the region 2 to 3.

Because an investigation of the fundamental relationship of the radiographic effect and the X-ray parameters was not of primary concern in the present contract, this study has not been pursued further.

- - - - -

* Bierman, A. and W. H. Boldingh, "The Relation Between Tension and Exposure Times in Radiography." Acta Radiologica 35, 22-5 (1951).

VI. CONCLUSIONS

An apparent amplification of 5 to 10 over the conventional ciné-fluorography system is possible with image-intensification tubes. With the camera used with the intensification systems modified so that the X-ray source may be pulsed, the radiation exposure to the patient is reduced by the same factor.

The small size of the input screens of the present image-intensifier tubes limits their use to the study of regions of interest smaller than about four-inches diameter. Philips has recently announced the production of an 11-inch diameter tube, however.

Resolution of simulated body components with the image-tube systems was equal to or better than all the other systems tested.

Areas where the present five-inch image tubes are particularly applicable are: infant angiocardiography, laryngeal-function studies, and other special studies of limited anatomical area. Even in these limited areas, the objections of the medical profession to the small viewing area must be considered. The conventional cinéfluorography system with its 10 by 14-inch viewing area is much less objectionable.

As the components of the television systems are improved, this type system may prove superior because remote monitoring by an unlimited number of people as well as electrical storage of information for future study will be possible.

VII. RECOMMENDATIONS

Complete image-intensifier tube systems are commercially available and in use in many hospitals. Therefore, it is doubtful if further explorations of the type under this contract are justifiable. There are several related fields, however, which could be explored. As pointed out in the text, there is no satisfactory mathematical formulation of the radiographic effect for the various systems. A study of this effect would be a real contribution to the science. Basic research in the field of direct conversion of X-rays to electrical signals would seem to be a promising approach to the problem of reducing the radiation to a patient.

The Emory University Medical School has conducted a research program in cinéfluorography for several years. Their facilities include a conventional cinéfluorography system which has recently been redesigned and rebuilt. They have acquired a General Electric TV-X direct-conversion system for use in their program. The special X-ray table which has been built by this project, the image-intensifier tubes and the related equipment would be invaluable in the continuing research program at Emory University if it were made available to them.

VIII. BIBLIOGRAPHY

Specific references have been given as footnotes in the text. The following items are of general interest and are cited here as an aid to the reader, although specific reference has not been made to them in the test.

Alphen, Burger, Oosterkamp, Jeves, und Tol, "Detailerkennbarkeit bei Durchleuchtung und Photographic mit der Bildverstarkerrohe." Fortschritte Auf Dem Gebiete Der Roentgenstrahlen Vereinigt Mit Roentgenpraxis, Band 77-Heft 4 (Oktober 1952).

Alter, W., "Sine Wave Versus Square Wave Relations." Westinghouse Research Memo, 60-94410-14-19.

Bierman, A., "A Systematic Method with New Standards to Determine the Correct Magnitude of Radiographical Exposures." Acta Radiologica 36, 311 (1951).

Bierman, A., and Boldingh, W. H., "The Relation Between Tension and Exposure Times in Radiography." Acta Radiologica 35 (1951).

Burger, G. C. E., "The Perceptibility of Details in Roentgen Examinations of the Lung." Medical Department, Philips Factories, Eindhoven, The Netherlands (1949).

Coltman, J. W., "Fluoroscopic Image Intensification by Electronic Means." Radiology 51, 359-76 (1948).

Coltman, J. W., "Scintillation Limitations to Resolving Power in Imaging Devices." Journal of the Optical Society of America 44, 3, 234-37 (1954).

Jacobs, J. E., and Berger, H., "Performance of a Large Area Photoconductive X-Ray Pickup Tube." X-Ray Department, General Electric Company.

Janker, R., "Roentgen Cinématography." American Journal of Roentgenology 36, 384-90 (September 1936).

Leverenz and Humbolt, "Luminescence of Solids." Wiley (1950).

BIBLIOGRAPHY (Continued)

Lindsay, D. and Sterm, B. E., "A New Tissue-Like Material for Use as a Bolus." British Journal of Radiology 60, 3, 355-62 (1953).

Marshall, Fitz-Hugh, "Microsecond Measurement of the Phosphorescence of X-Ray Fluorescent Screens." Journal of Applied Physics 18, 6, 512-18 (1947).

Marshall, Fitz-Hugh, "Developments in Electronic X-Ray Fluoroscopy." NOLR 1147 (1 July 1950).

Moon, R. J., "Discussion of Symposium on Screen Intensification." American Journal of Roentgenology 62, 637-43 (1949).

Moon, R. J., "Amplification and Intensification of the Fluoroscopic Image by Means of a Scanning X-Ray Tube." Science 112, 389-95 (1950).

Nelson, A., "Determination of Physical Factors Influencing the Quality of the Radiographic Image." Acta Radiologica Supplementum 76.

Pringsheim, P., "Fluorescence and Phosphorescence." Interscience (1949).

Ramsey, G. H. S., et. al., "Cinéfluorography." Radiology 52, 684-90 (1949).

Reynolds, R. J., "Cinéradiography." American Journal of Roentgenology 33, 522-28 (April 1935).

Rice, F. O., and Teller, E., "Structure of Matter." Wiley.

Rushman, R. F., Bark, R. S., and Hendron, J. A., "Clinical Cinéfluorography." Radiology 55, 588-92 (1950).

Spiers, F. W., "Materials for Depth Dose Measurement." British Journal of Radiology 16, 183 (March 1943).

Stewart, W. H., Hoffman, W. J., and Ghiselin, F. H., "Cinéfluorography." American Journal of Roentgenology 38, 465-69 (September 1937).

BIBLIOGRAPHY (Continued)

Van Allen and Morgan, "Measurement of Resolving Power of Intensifying Screens." American Journal of Roentgenology 47, 166-74 (1946).

Warren, J. C., and Weens, H. S., "Hemodynamic Studies Utilizing the Technique of Cinéangiocardiography." U. S. Public Health Service Research Grant No. H-210(c) (September 1949 to February 1954).

Watson, J. S., and Weinberg, S., "A 35-mm Unit for Cinéfluorography." Radiology 51, 728-32 (1948).

Watson, J. S., Weinberg, S., and Ramsey, G. H., "A 70-mm Cinéfluorographic Camera and Its Relation to Detail." Radiology 59, 848-65 (December 1952).

Weinberg, S., "Technical Refinements in Cinéfluorography." American Journal of Roentgenology 75, 63-68 (January 1956).

Weinberg, S. A., Watson, J. S., and Ramsey, G. H., "X-Ray Motion Picture Techniques Employed in Medical Diagnosis and Research." Journal of the S.M.P.T.E. 59, 300-08 (October 1952).

Weinberg, S. A., Watson, J. S., and Ramsey, G. H., "X-Ray Motion Picture Camera and Printer for 70-mm Film." Journal of the S.M.P.T.E. 60, 31-7 (January 1953).

Wynne, C., "A New Form of f/0.71 Lens for 35-mm Ciné-radiography." Journal of Scientific Instruments 28, 172-73 (1951).

X-Ray Research and Development, Volume II, N. V. Philips Gloeilampenfabrieken, Eindhoven, The Netherlands. Waterlow and Sons, Ltd., London and Dunstable.

X-Ray Research and Development, Volume III, N. V. Philips Gloeilampenfabrieken, Eindhoven, The Netherlands (1937-1950).